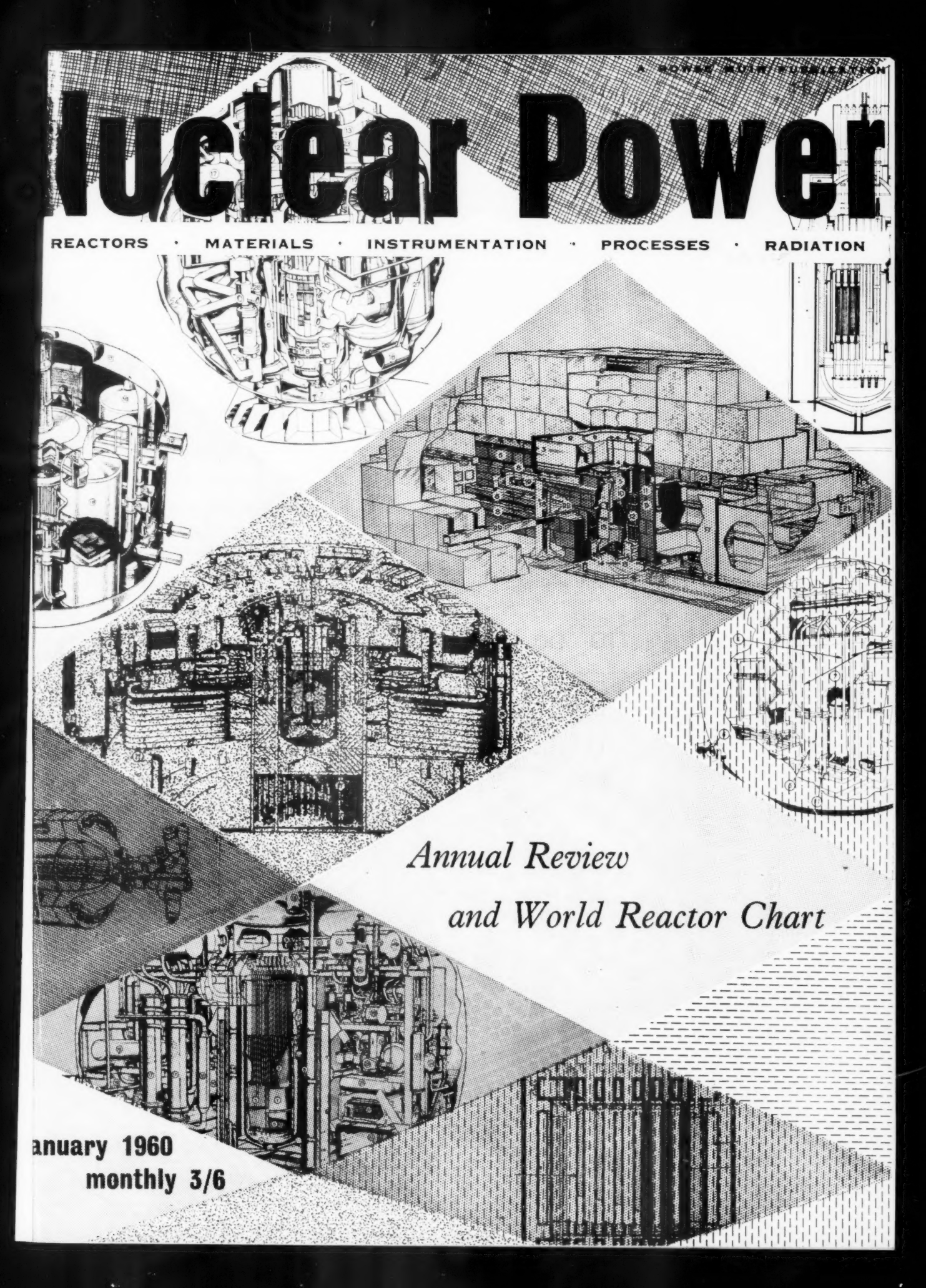
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Nuclear Power
REACTORS · MATERIALS · INSTRUMENTATION · PROCESSES · RADIATION
Annual Review
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anuary 1960
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REACTORS · MATERIALS · INSTRUMENTATION · PROCESSES · RADIATION

VOL 5 NO 45 JANUARY 1960

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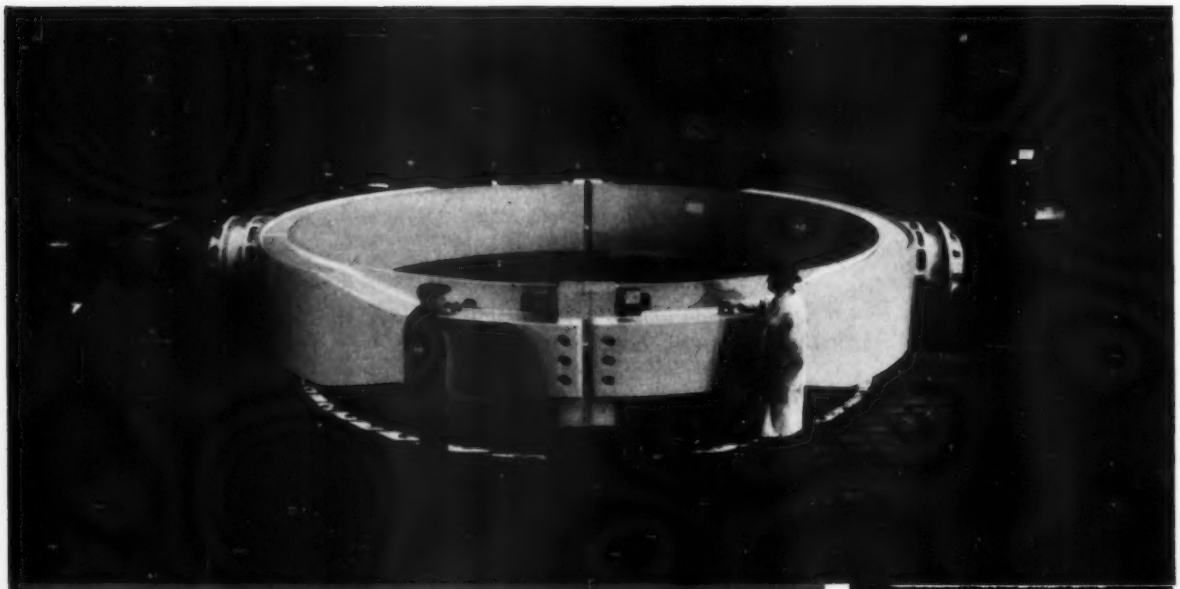

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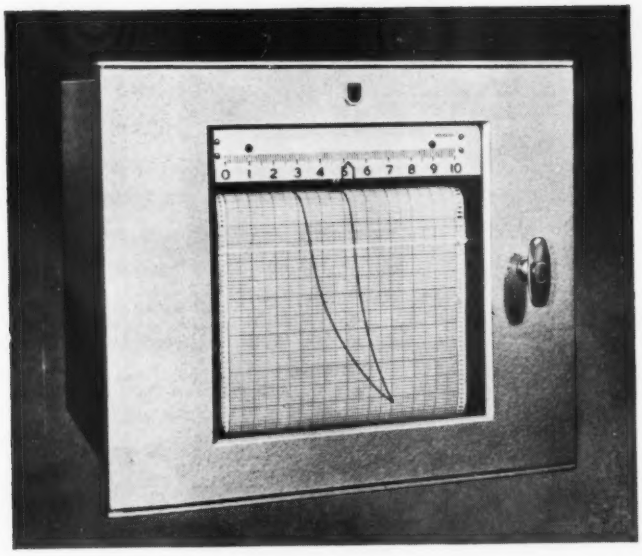

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Amplifier	*A.C. amplifier, plug-in type.*
Permissible input impedance	*400Ω/mV of measuring range selected**
Permissible D.C. voltage across input terminals and earth	*1000 x span, 100 V maximum**
Permissible A.C. voltage	*across input terminals 0.001 x span; across input terminals and earth 100 x span**

** Criterion of reproducibility 0.1%.*

Y-CHANNEL

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Graduation of scale	*linear from 0 to 100.*
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Scale	*preprinted strip chart.*
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Response time	*2 sec.*
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MEASURING RANGES Y-CHANNEL	X-CHANNEL
0..... 5 mV	
0..... 10 mV	
0..... 20 mV	0..... 20 mV
0..... 50 mV	0..... 50 mV
0.....100 mV	0.....100 mV
0.....200 mV	0.....200 mV
0.....500 mV	0.....500 mV

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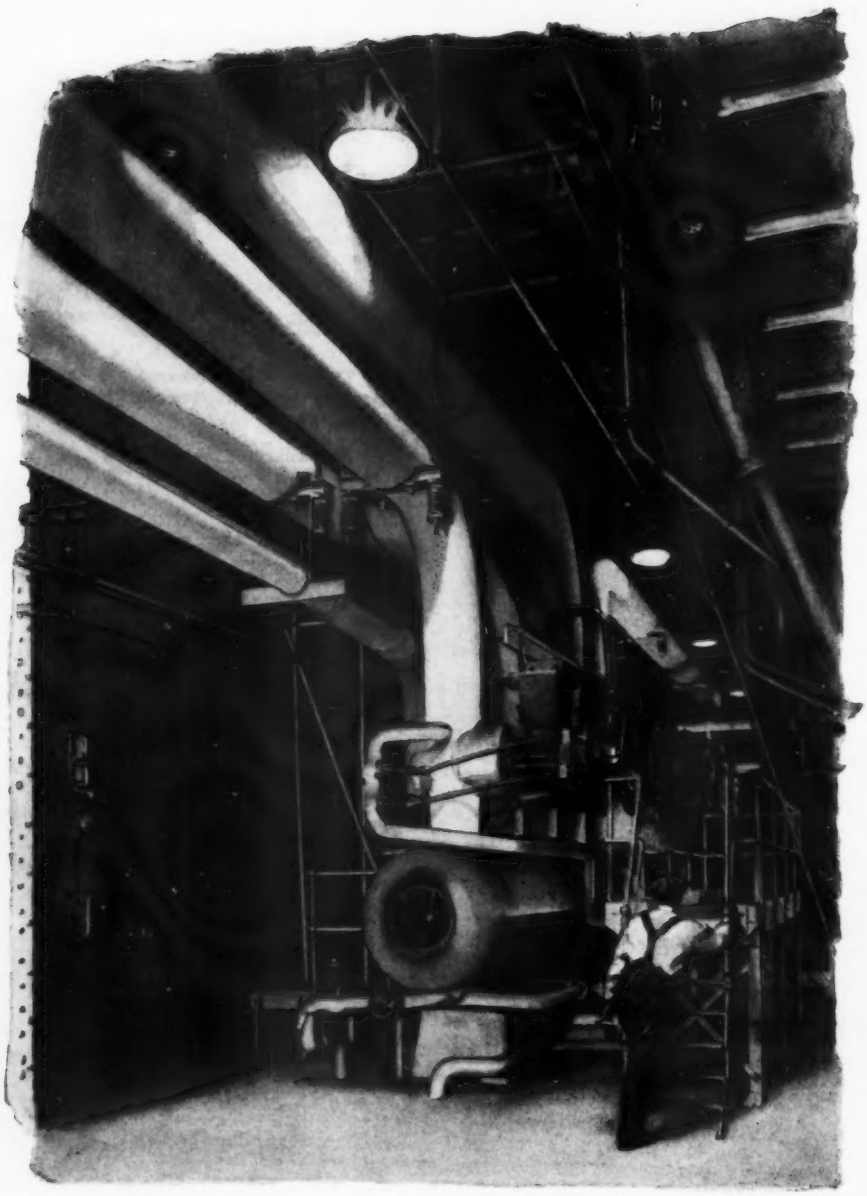

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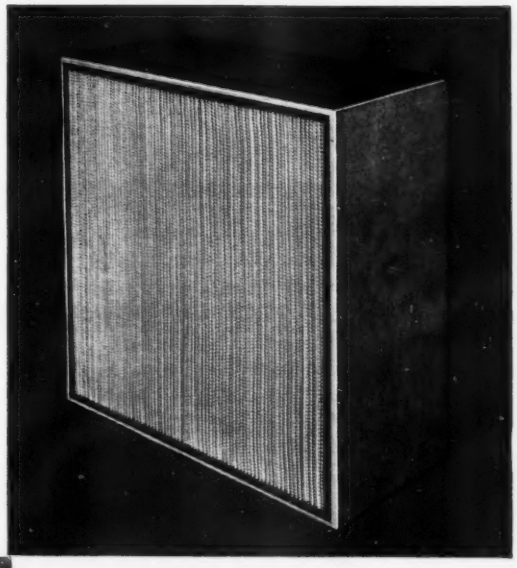

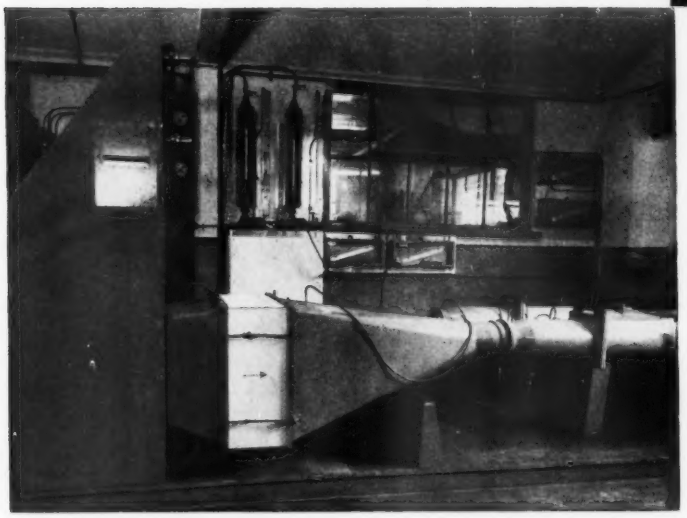

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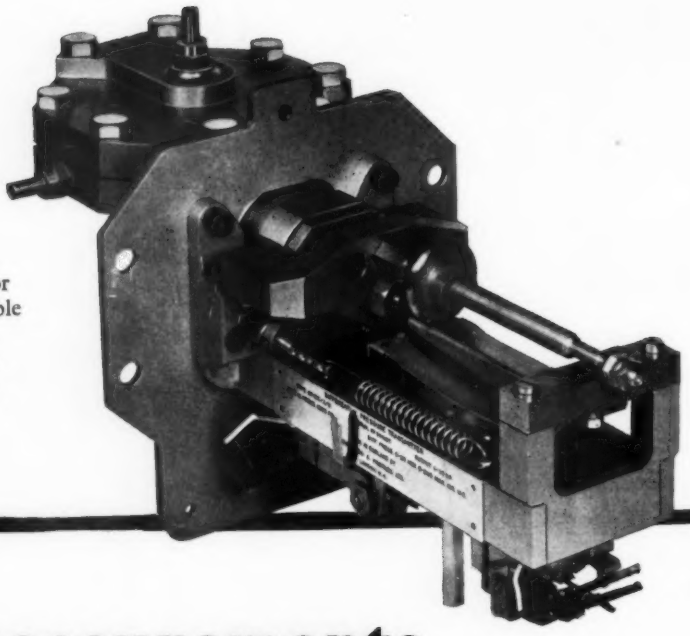

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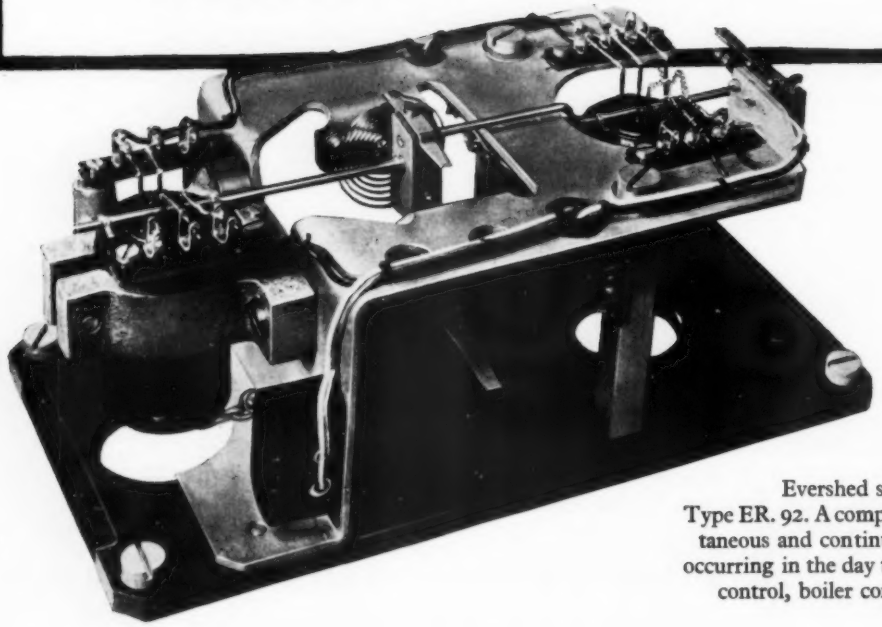

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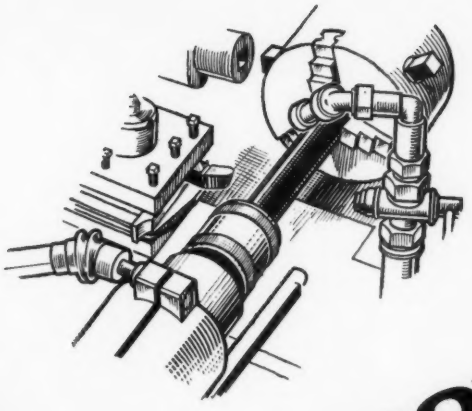

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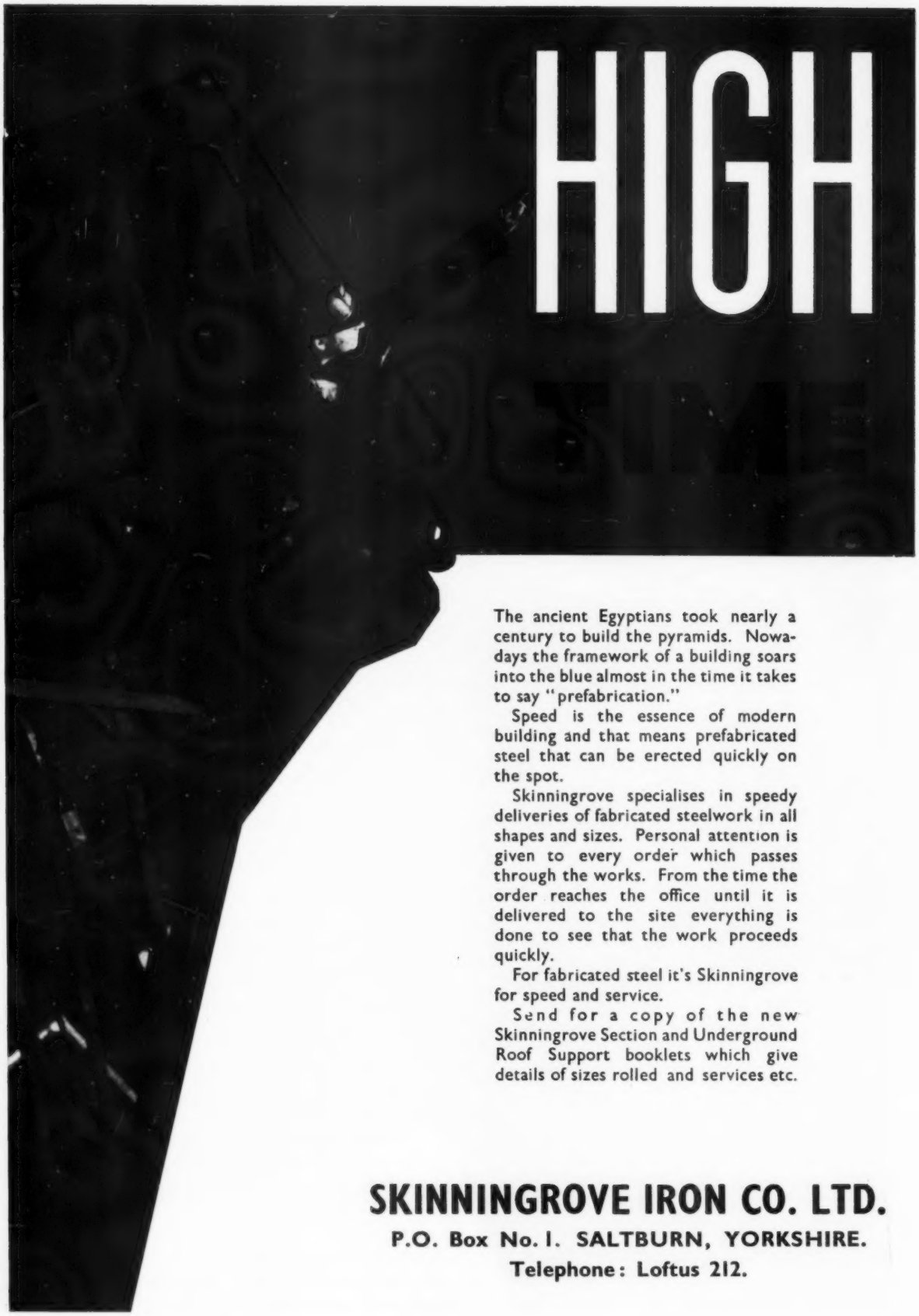

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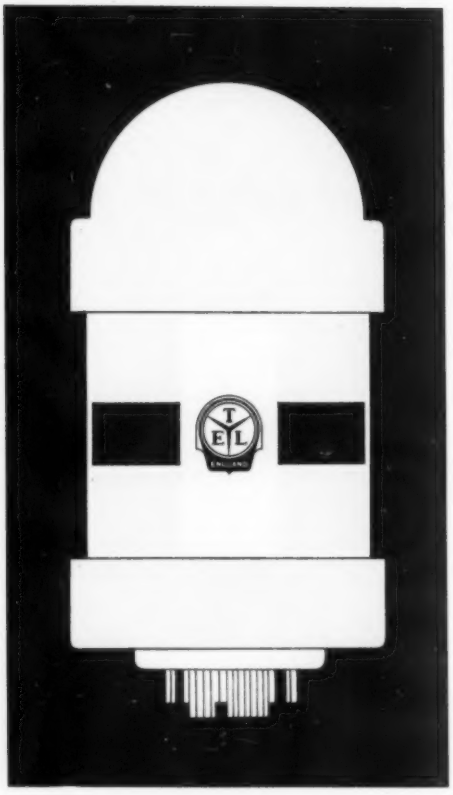

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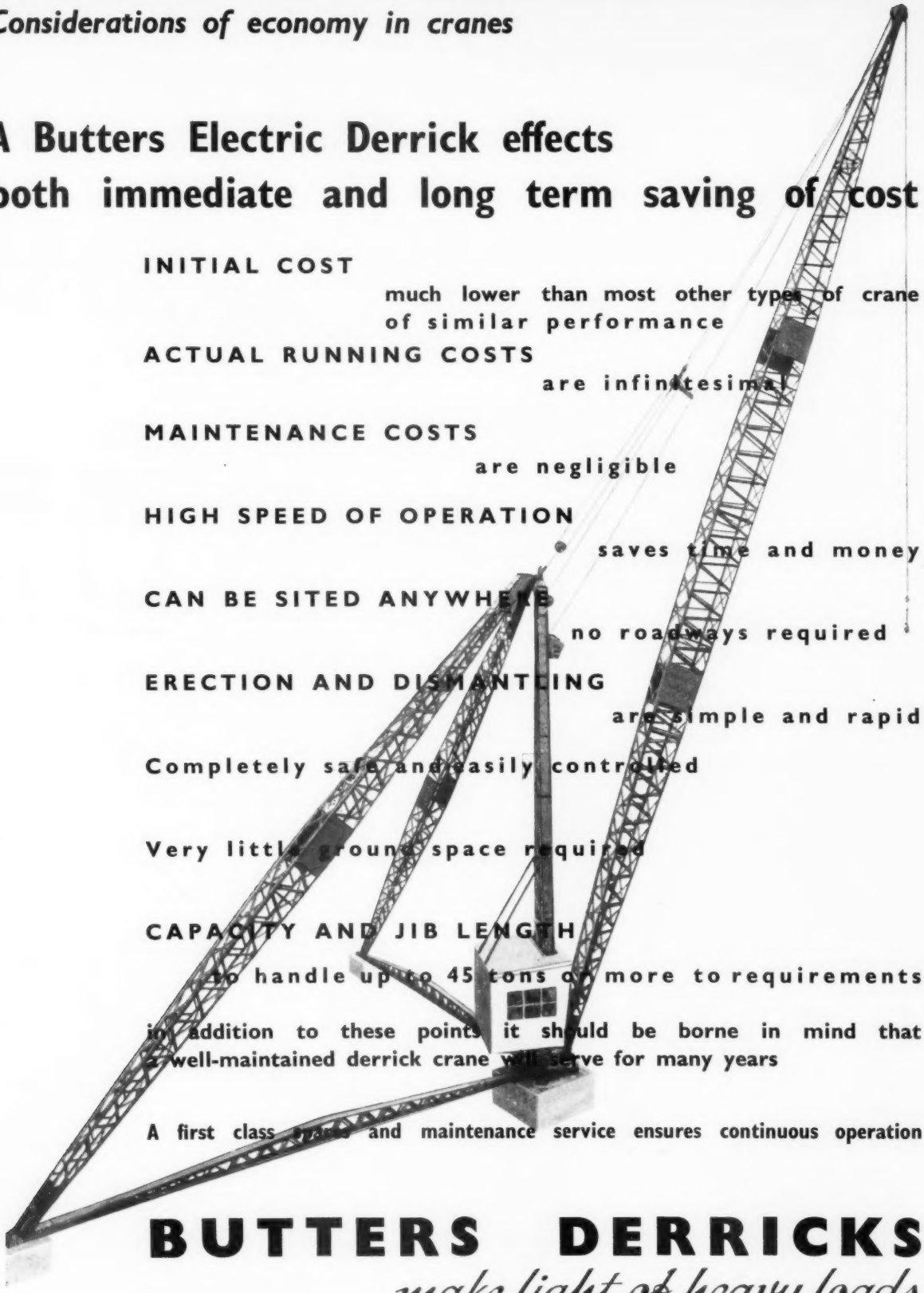

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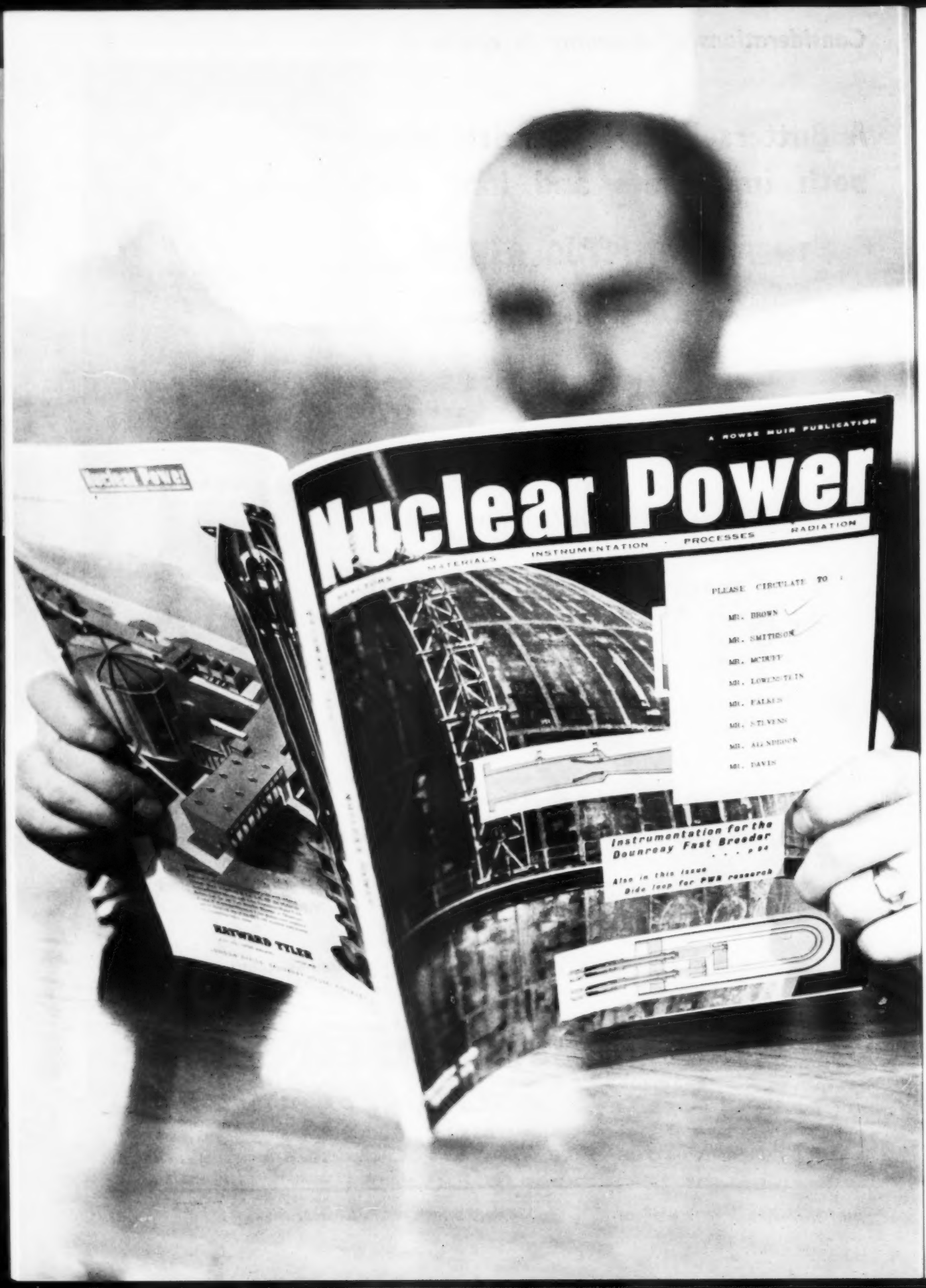
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. . . p 94
Also in this issue
Dido loop for PWR research
HAYWARD TYLER

Mr. Davis is scheduled to be a bit behind

For three weeks *Nuclear Power* lay buried on Mr. Brown's desk.

Then Mr. Smithson became interested in a treatise on two-group theory that he never actually got round to. That took fourteen days.

Now the *real* readers will be in possession for months. Mr. McDuff, here, has spilt coffee on page 22 and abstracted some graphs that specially caught his eye on page 29.

By the time our magazine reaches Mr. Davis it won't be what it was. Pity—because of all these people Mr. Davis is potentially the most brilliant. The sooner he fills in the pre-paid subscription card facing page 166 the better. After all, a personal copy of *Nuclear Power* costs only 3/6 a month.

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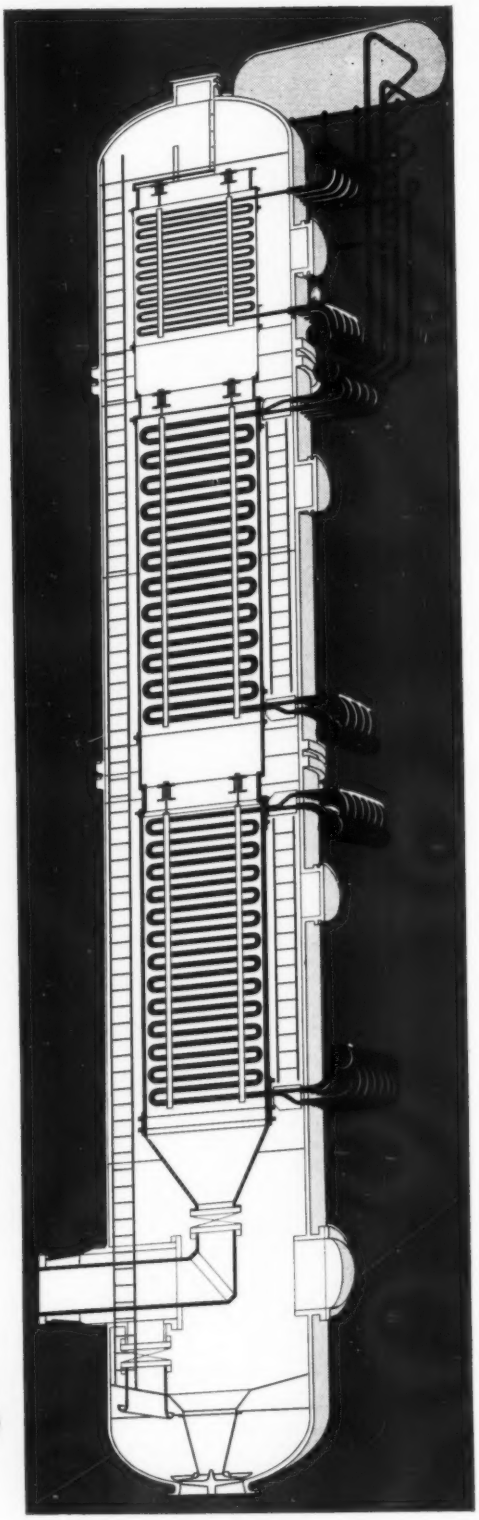

A sectional model of one of the heat exchangers for the Atomic Energy Authority's plant at Windscale

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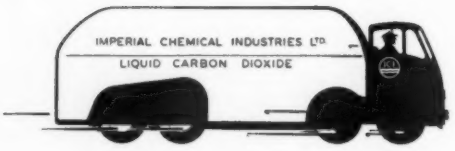

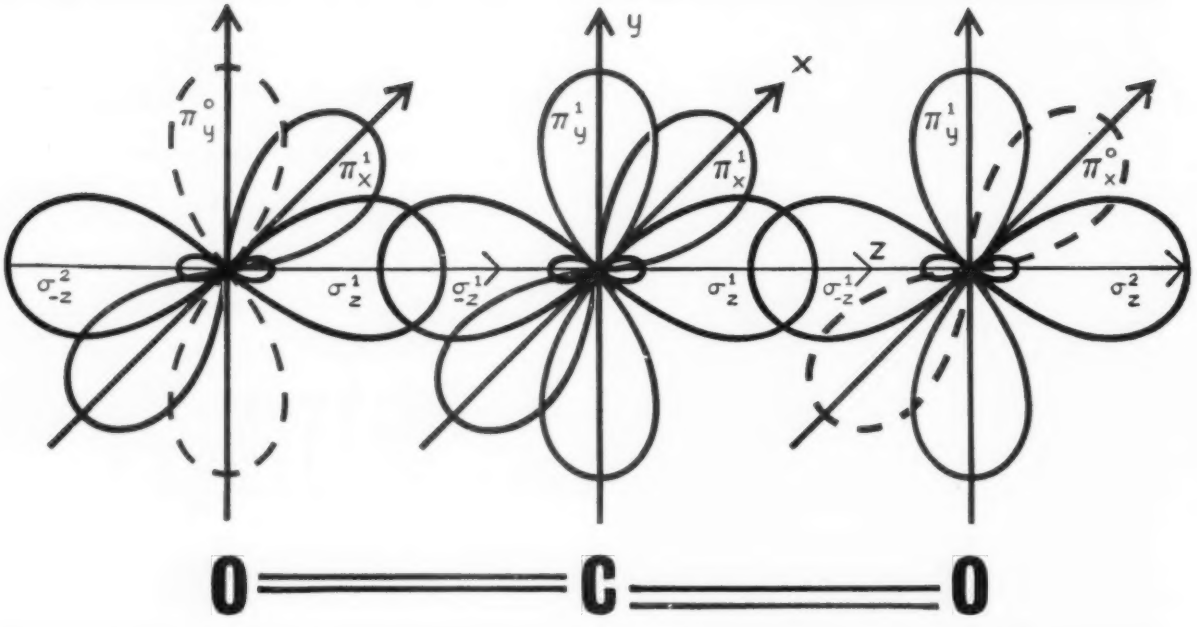

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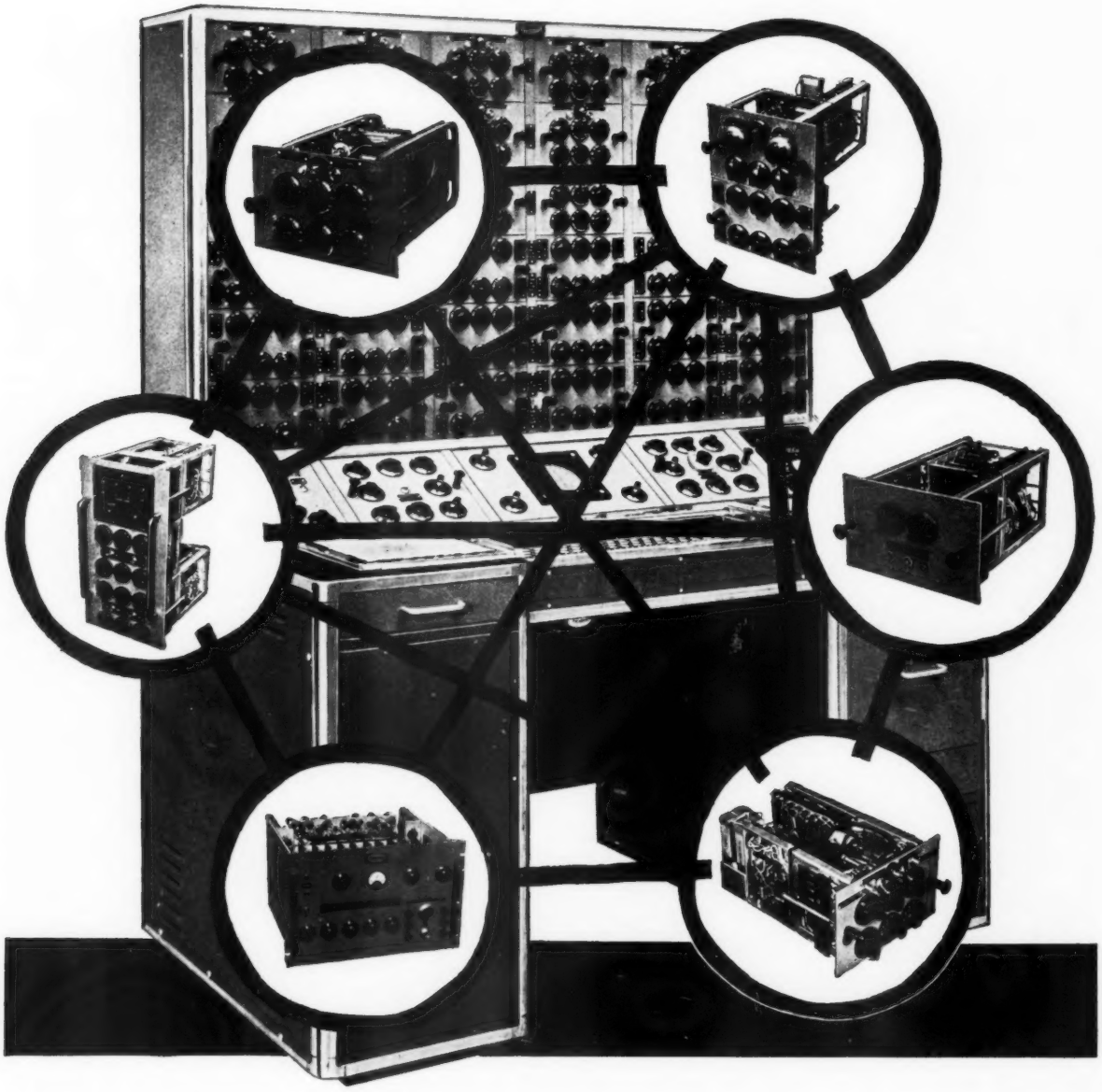

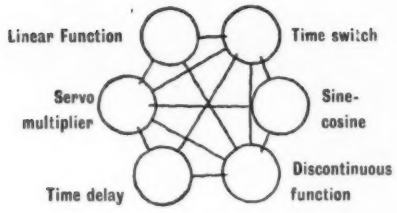

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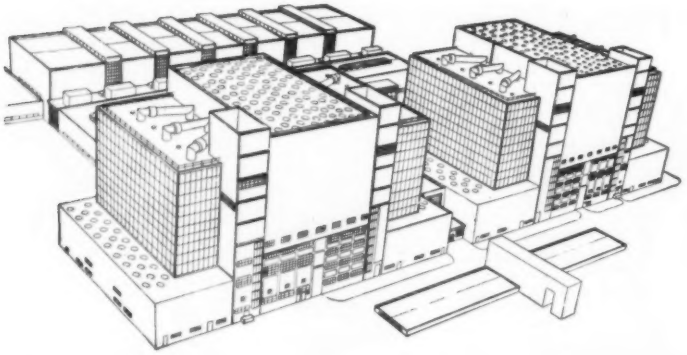

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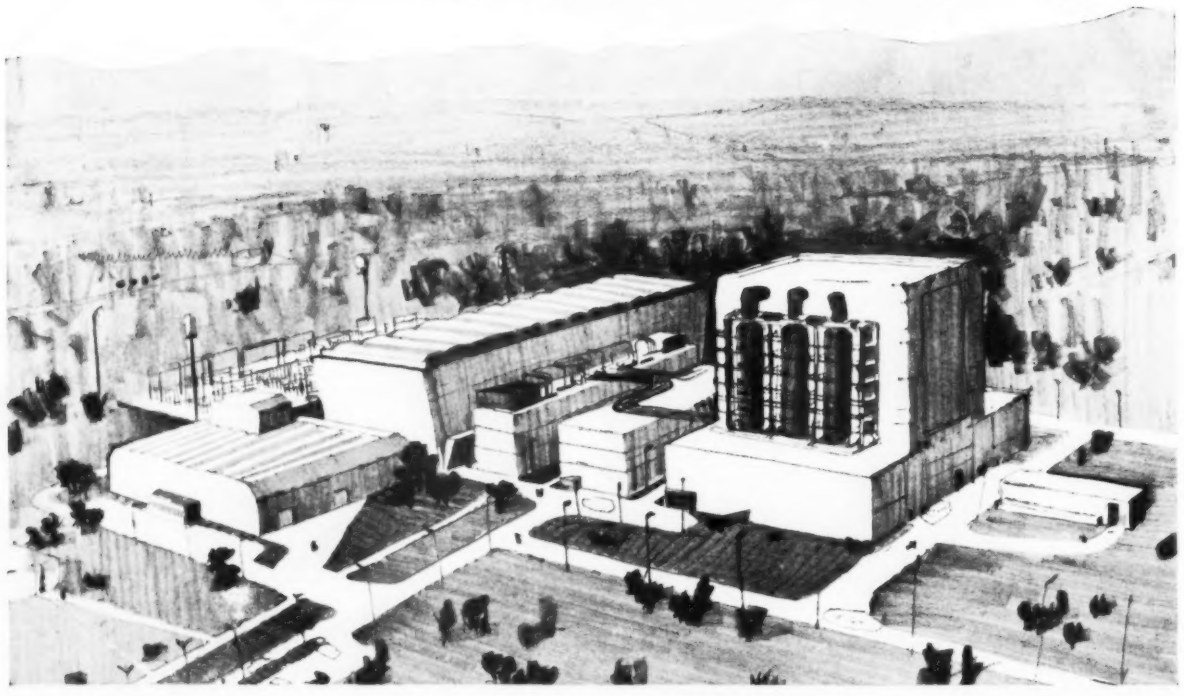

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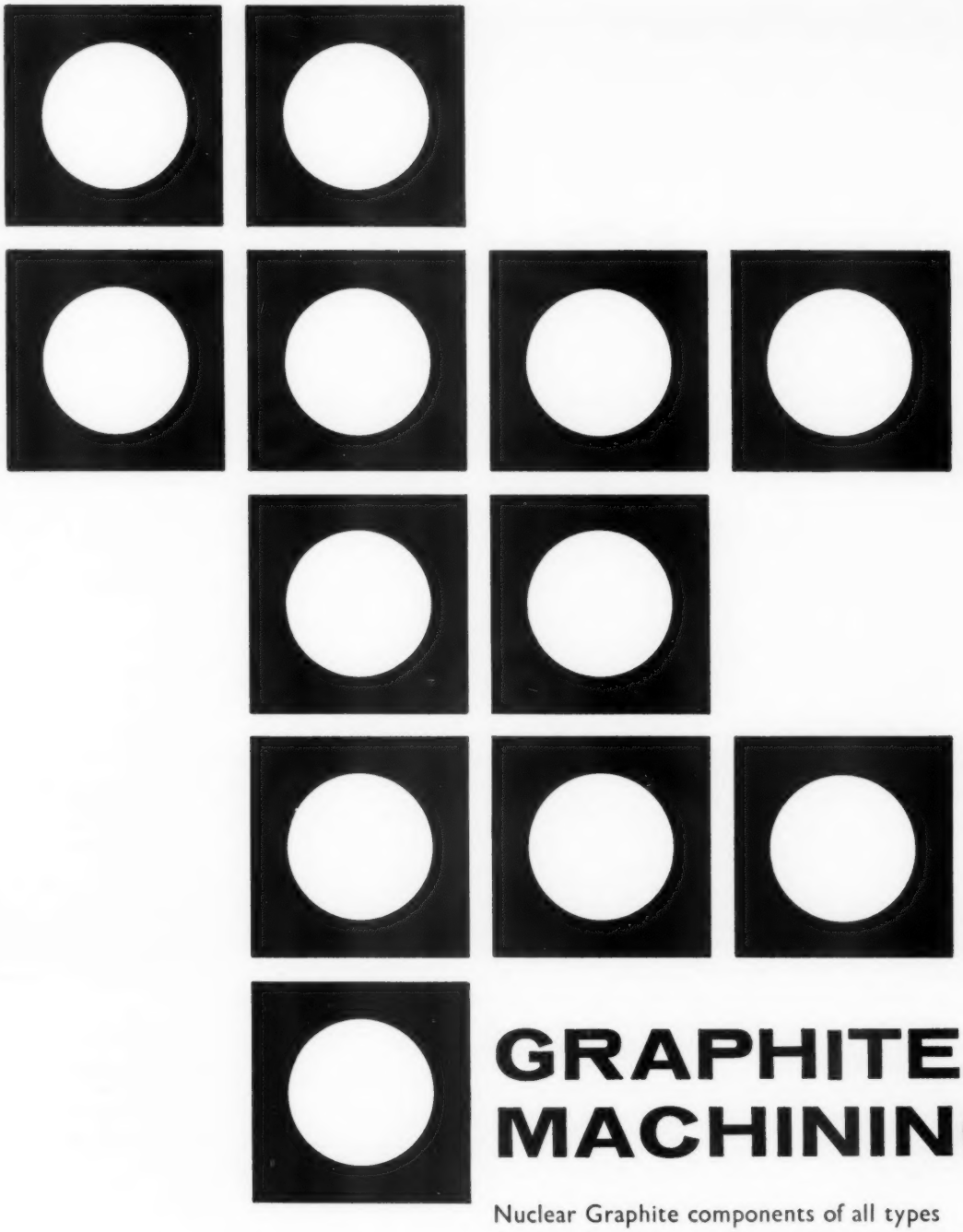

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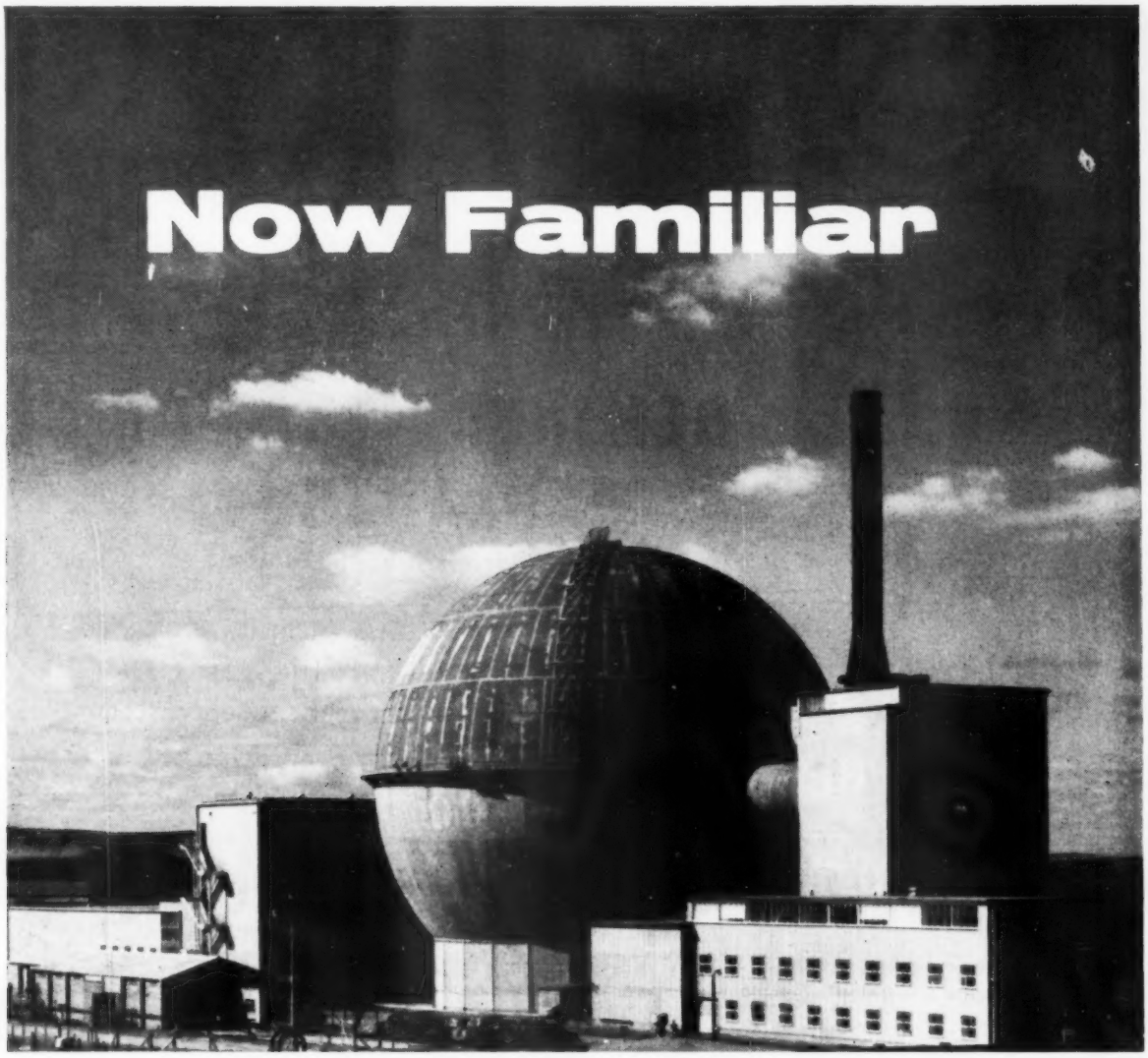

The silhouettes of the atomic pov r stations, strange and new a year or two ago, are today familiar to tec' cal men.

Keeping pace with new develo_ ients for over 75 years, 'Tornado' fan engineering equipment now finds itself quite at home in these strange landscapes, assisting in the exacting work of the UKAEA establishments. Among the equipment we have supplied for Dounreay is fan equipment for the vessel ventilation system, the Highly Active Liquor Store and the Billet Production Plant.

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2 IMPORTANT DEMINERALISATION PLANTS

William Boby & Co. Ltd. have been entrusted with the execution of the demineralisation water treatment plants at:

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The plant comprises the following sections:

Coagulation and Settlement — Filtration — Cation Exchange — Weakly basic Anion Exchange — Degassing — Mixed Bed Ion Exchange.

2 VEITSILUOTO O/Y, Finland

The Veitsiluoto paper mills of Finland have installed a 13,400 galls/hr. 'Boby' demineralisation water treatment plant for feed water for boiler working at 1,750 p.s.i.

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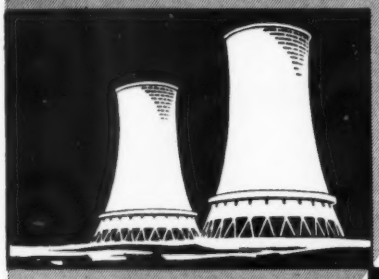
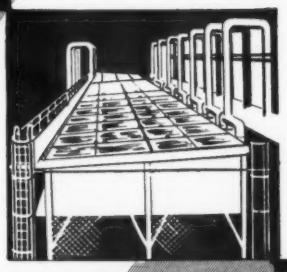
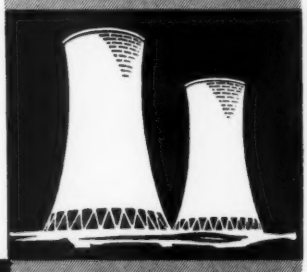


NATURAL DRAUGHT COOLING TOWER

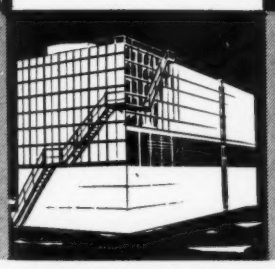
NATURAL DRAUGHT HEAT EXCHANGER





MECHANICAL DRAUGHT HEAT EXCHANGER

MECHANICAL DRAUGHT COOLING TOWER



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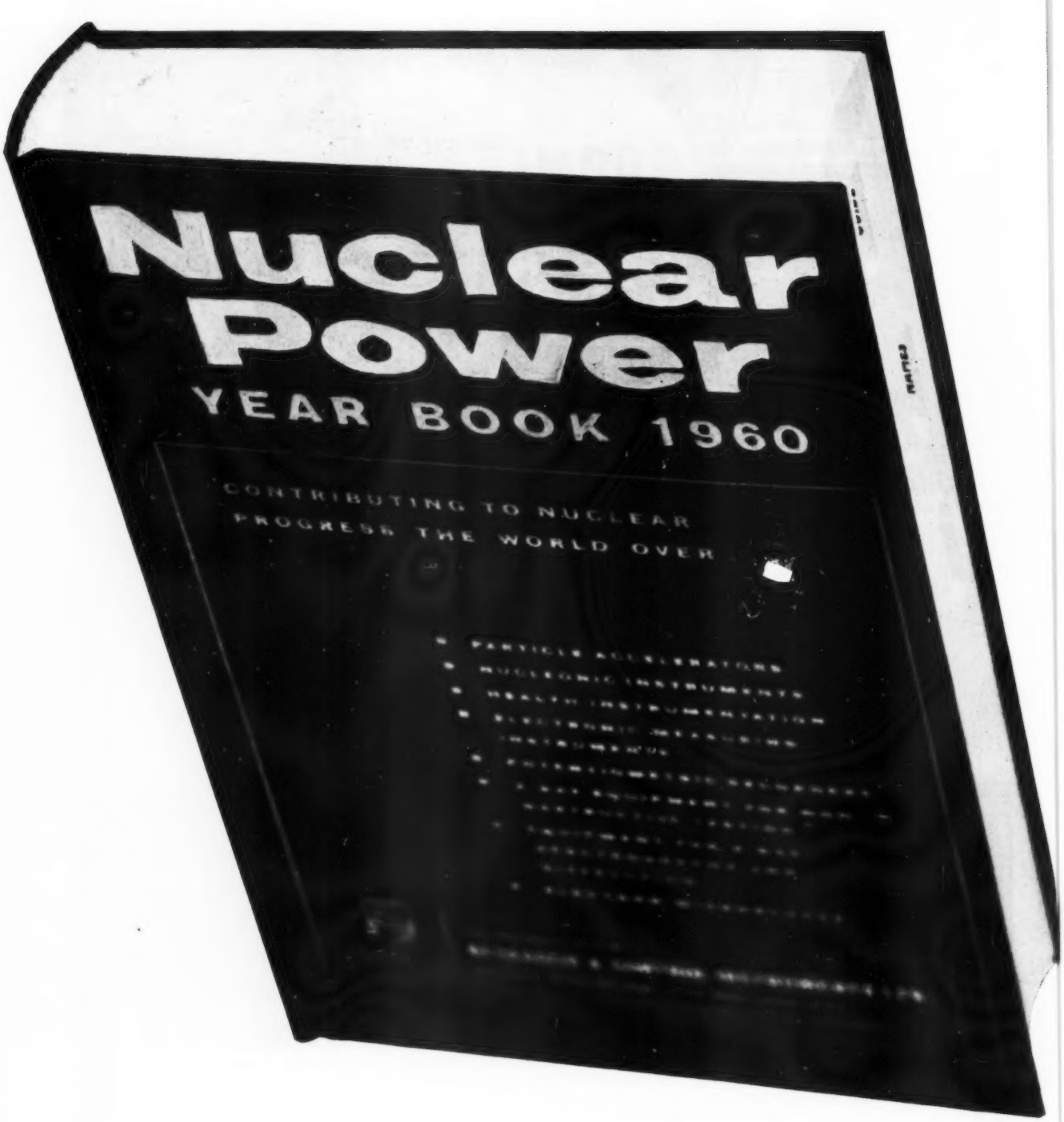
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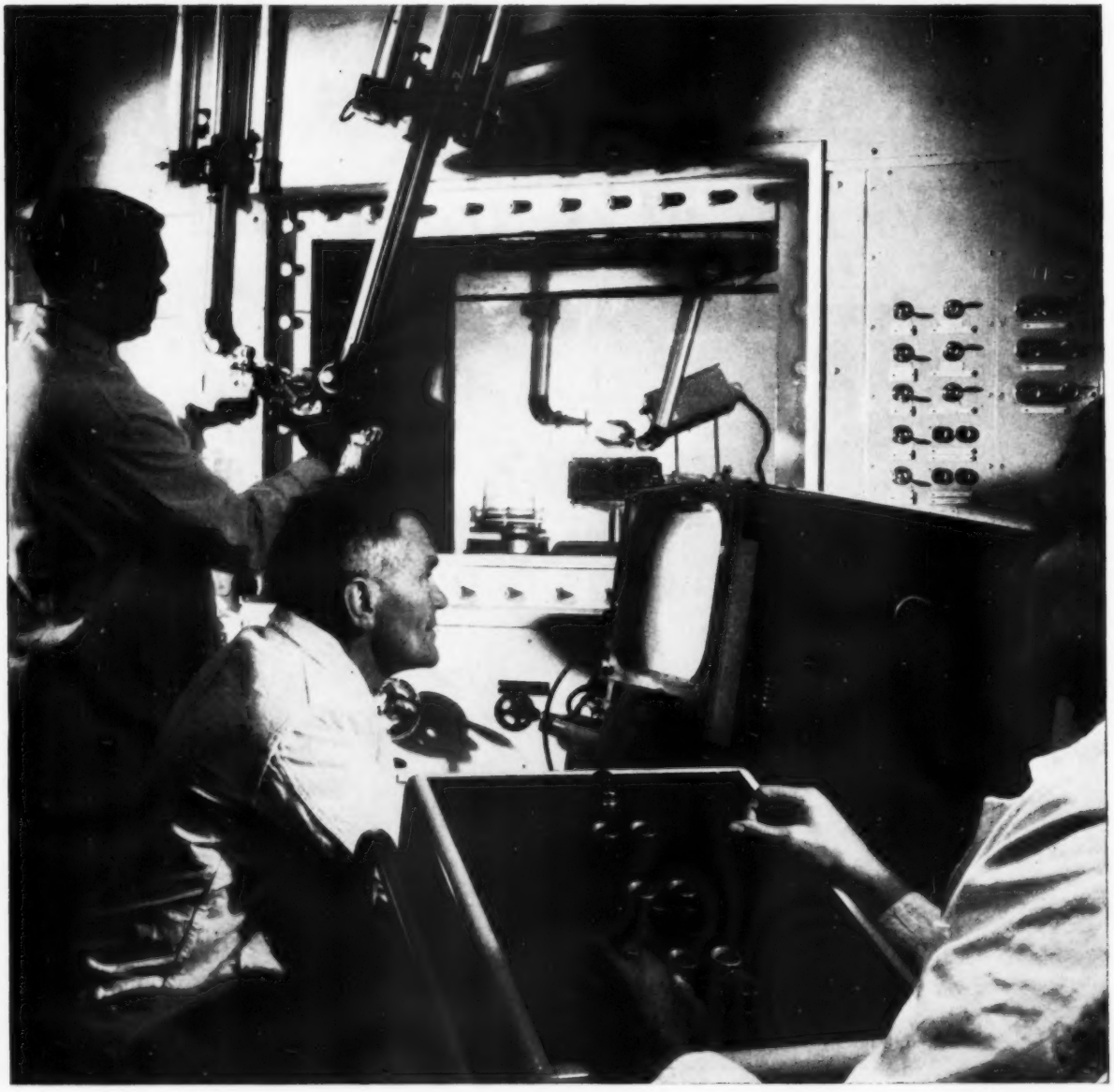

Pye at Dounreay

The Pye Instrument Group has supplied all the equipment to the U.K. Atomic Energy Authority for the irradiated fuel element laboratory at Dounreay. In addition to supplying equipment, Pye Ltd. acted as consultants and designers on all matters in that laboratory relating to instrumentation and remote handling. The illustration above shows manipulators working in conjunction with a television camera to handle and measure a sample from the fast reactor.

The Pye Instrument Group consists of : Pye Atomics Division ; Pye Industrial Television Division ; Faraday Electronic Instruments Ltd.; Labgear Ltd.; W. G. Pye & Co. Ltd.; Pye Telecommunications Ltd.; Unicam Instruments Ltd.; W. Bryan Savage Ltd.; W. Watson & Sons Ltd.

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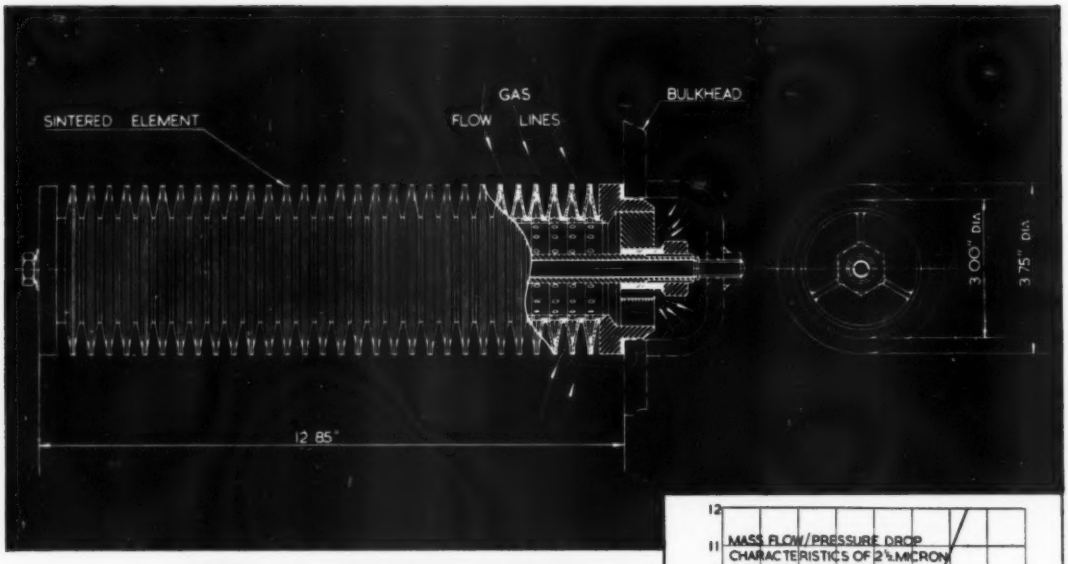

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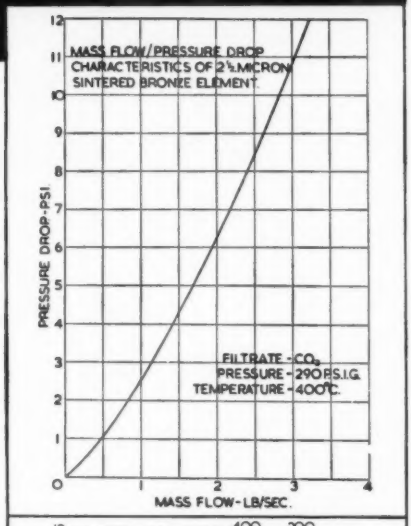
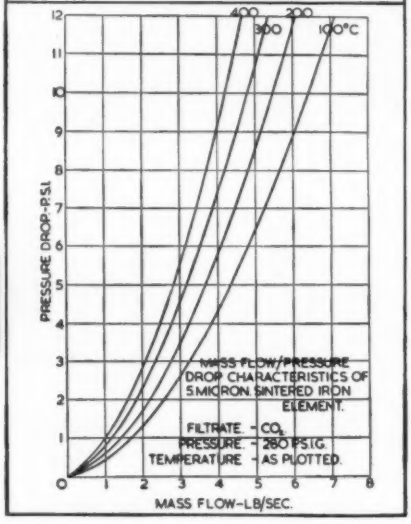
Further details on request


MASS FLOW/PRESSURE DROP CHARACTERISTICS OF 2½ MICRON SINTERED BRONZE ELEMENT.
FILTRATE - CO_2
PRESSURE - 290 P.S.I.G.
TEMPERATURE - 400°C.
PRESSURE DROP-PSI
MASS FLOW-LB/SEC.



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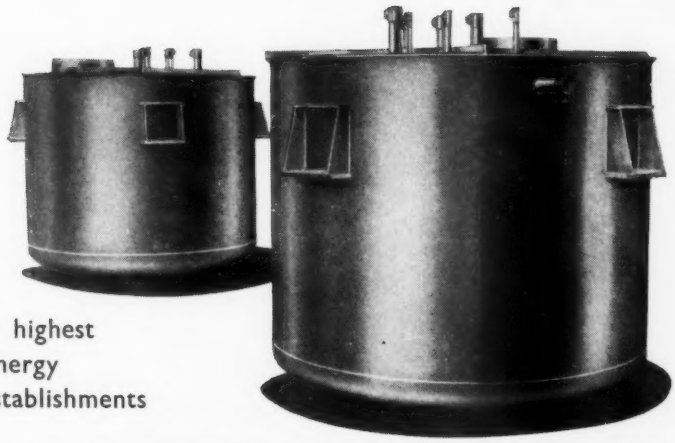

ILLUSTRATED ABOVE

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AND LEFT

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DIESEL-ELECTRIC

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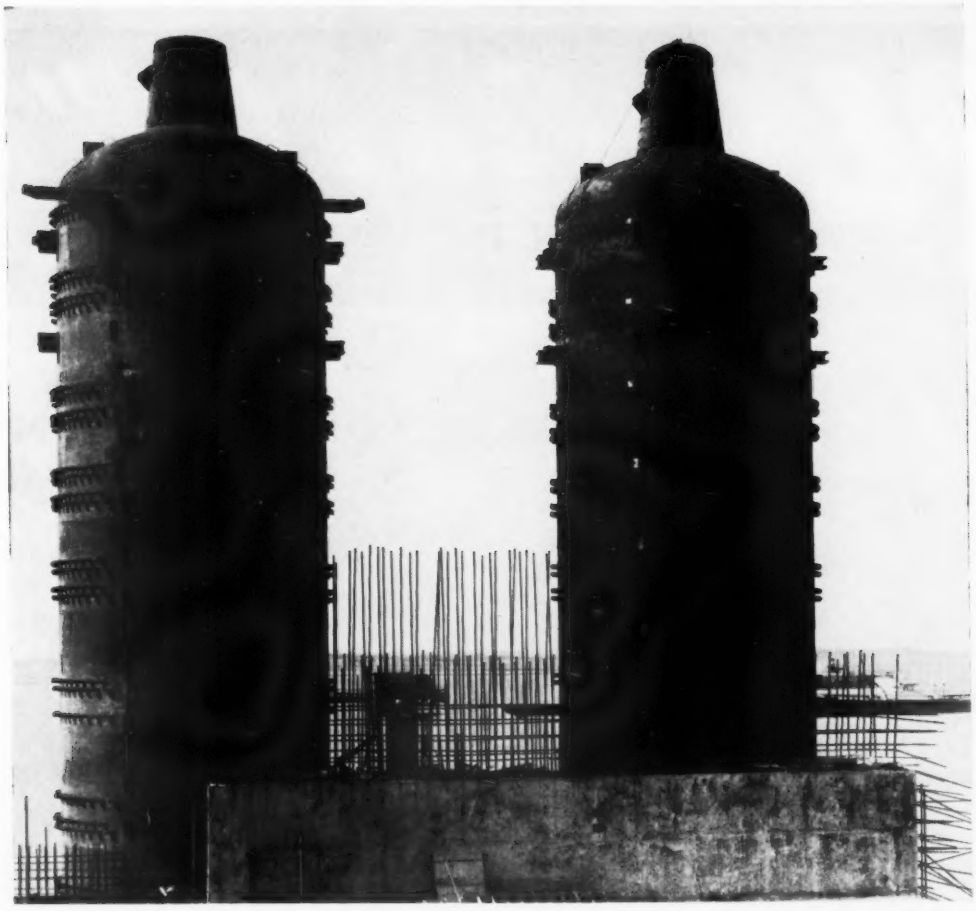

Every inch is seen to be perfect

The heat exchangers for the Bradwell station are so large they had to be towed to the site by sea.

There are 12 of these exchangers, designed and manufactured by Head Wrightson & Co. Ltd. Each weighs 200 tons and includes low-pressure and high-pressure systems.

The shells of the exchangers consist of four circumferential plates in 12 tiers. The plates are first tack-welded into place and the internal and external longitudinal welds are then made with automatic submerged-arc sets to Lloyds Class 1 specifications. Every inch of every weld is then X-rayed.

The dished ends, consisting of eight segments pressed to shape, are hand-welded, double-U preparations being used. The reinforcing ring outlets and flanges are then welded into position and X-rayed.

The importance of the radiographic inspection on a project of this magnitude cannot be over-emphasised. Not only must every inch of every weld be perfect—it must be *seen* to be perfect. That is why Kodak 'Industrex' X-ray Films were used exclusively for the heat exchangers of Bradwell Nuclear Power Station.

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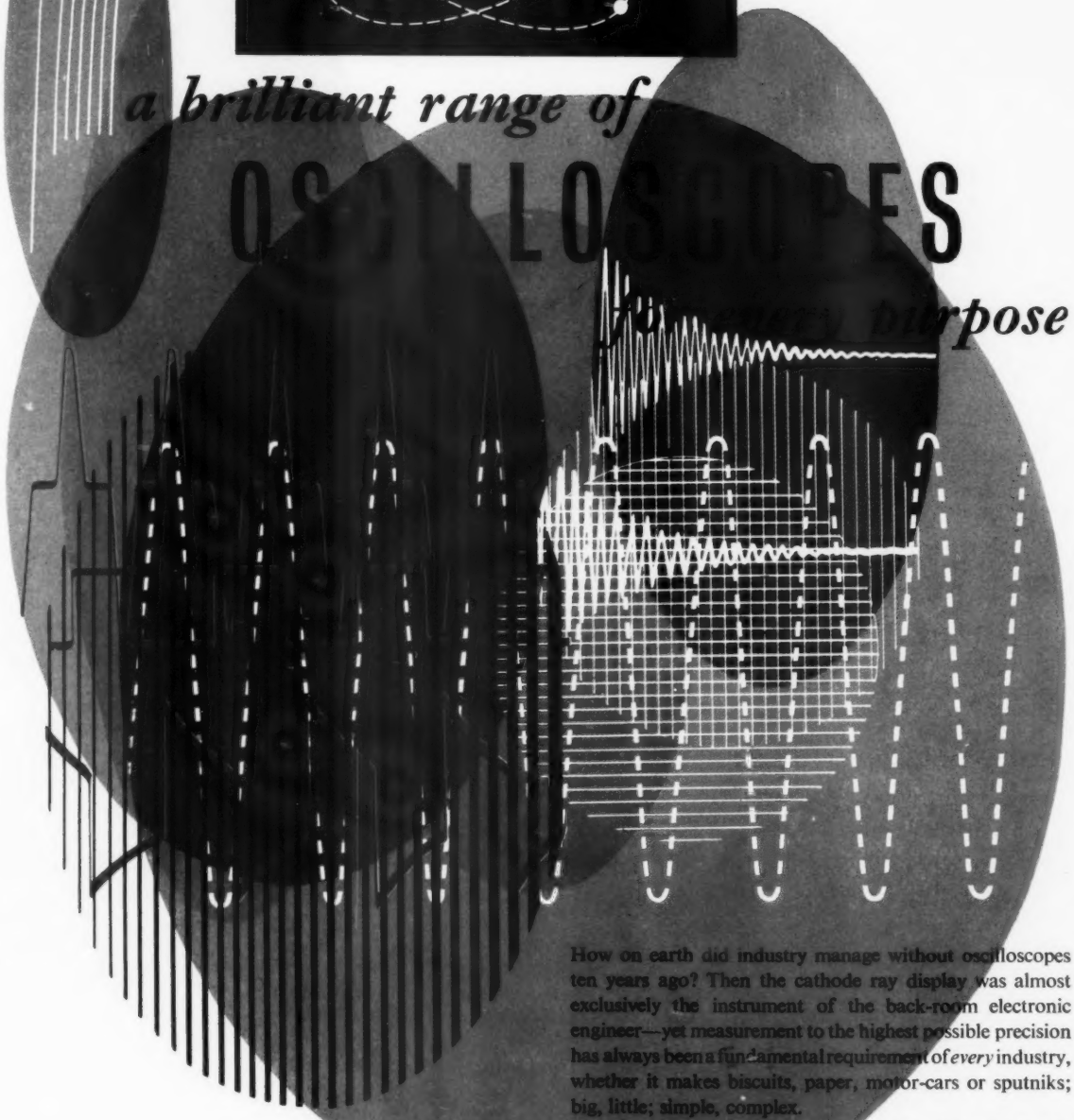

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FIELD AND SERVICE USE

GENERAL-PURPOSE

How on earth did industry manage without oscilloscopes ten years ago? Then the cathode ray display was almost exclusively the instrument of the back-room electronic engineer—yet measurement to the highest possible precision has always been a fundamental requirement of *every* industry, whether it makes biscuits, paper, motor-cars or sputniks; big, little; simple, complex.

The most significant development of the past decade has been this startling glimpse of the obvious—that the oscilloscope is now the standard measuring instrument of every industry, in the plant not just in the "back room", as automatically accepted as the micrometer, the weighing balance or the thermometer.

Overleaf we have presented ten outstanding oscilloscopes of the Solartron range in a form which we hope will be helpful in deciding the right model for your field of activity. But remember too, that expert advice is freely available from Solartron, who make more 'scopes than anyone in Europe.

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OSCILLOSCOPE

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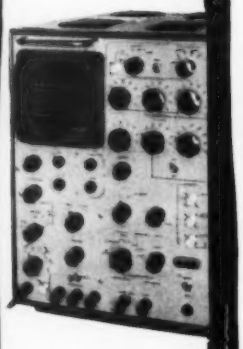
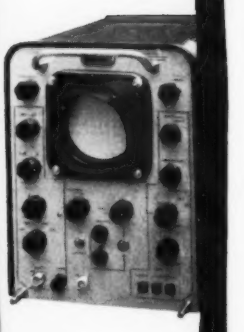


The most accurate measuring oscilloscope in production today, the Solartron CD 643S measures time and amplitude to better than 2% over a bandwidth of DC to 12 Mc/s.

For field or Services' use the comprehensive user facilities and wide time-base range provided in the CD 523S.2 make this a particularly versatile general-purpose oscilloscope.



Lightweight and portable, the new CD 814.2 constant-bandwidth 'scope is equally suitable for technical training or servicing of TV and other complex electronic equipment.

FIELD & SERVICE USE JOINT SERVICE APPROVAL

These three oscilloscopes have full Joint Service Approval. This is only granted after exhaustive testing of production oscilloscopes to Specification K 114E — a series of stringent vibration and environment tests especially framed by the Ministry of Supply to ensure peak reliability of Service equipment under all field conditions.

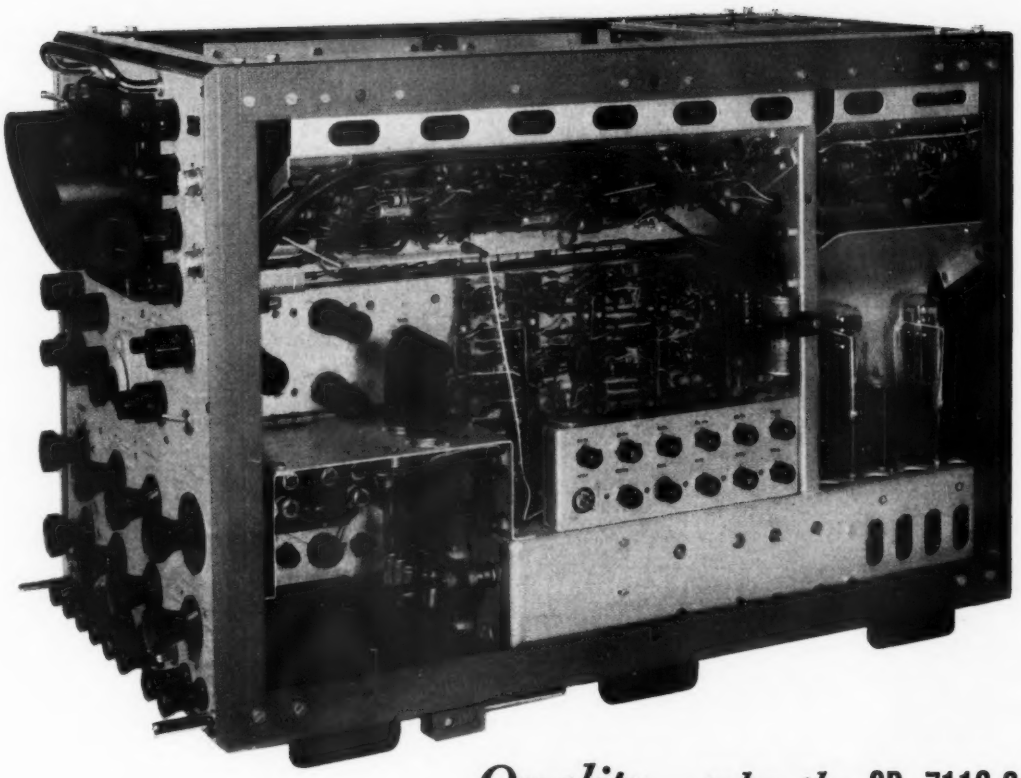
PULSE WORK

CD 711S.2	CD 643S	CD 523S.2	QD 910
JOINT SERVICE No.: CT414	JOINT SERVICE No.: CT 350	JOINT SERVICE No.: CT 356A	
BANDWIDTH: DC to 7 Mc/s (Y_1 and Y_2)	BANDWIDTH: DC to 12 Mc/s.	BANDWIDTH: DC to 10 Mc/s.	BANDWIDTH: DC to 1 Mc/s (Y_1 and Y_2).
MAX. SENSITIVITY: 3 mV/centimetre.	MAX. SENSITIVITY: 100 mV/centimetre. Constant bandwidth.	MAX. SENSITIVITY: 1 mV/centimetre.	MAX. SENSITIVITY: 10 mV/centimetre. Constant bandwidth.
SENSITIVITY AT MAX. BANDWIDTH: 10 V/centimetre.		SENSITIVITY AT MAX. BANDWIDTH: 10 V/centimetre.	TIME BASE RANGE: 1 μSec/cm—10 Sec/cm.
TIME BASE RANGE: (inc. expansion) 0.03 μSec/cm. to 3 Sec/cm.	20 mμSec/cm—100 mSec/cm.	TIME BASE RANGE: (inc. expansion) 0.02 μSec/cm— 1 Sec/cm.	CALIBRATION ACCURACY: 5% velocity. 5% amplitude.
CALIBRATION ACCURACY: 5% velocity, also crystal cal. markers. 5% amplitude	CALIBRATION ACCURACY: 2% velocity (markers). 2% velocity (bright-up pedestal). 2% amplitude (cal. shift).	CALIBRATION ACCURACY: 10% velocity. 10% amplitude.	T.B. TRIGGER DELAY: 10 μSec to 100 Sec.
ADDITIONAL FACILITIES: Trigger delay 10 μSec. to 10 mSec. 0.5 μSec signal delay. Direct access to plates. 'Z' modulation input.	ADDITIONAL FACILITIES: 'Z' modulation input. Up to x100 'X' expansion. Calibration is by precision triple-decade switching. Direct access to plates. 0.5 μSec. signal delay.	Socket for power probe.	Push-button or auto-erase time is 0.2 Sec. 'Z' modulation input. Triggering from ext., int., or push-button, or via delay generator.

EDUCATION

GENERAL PURPOSE

RADAR and Communications

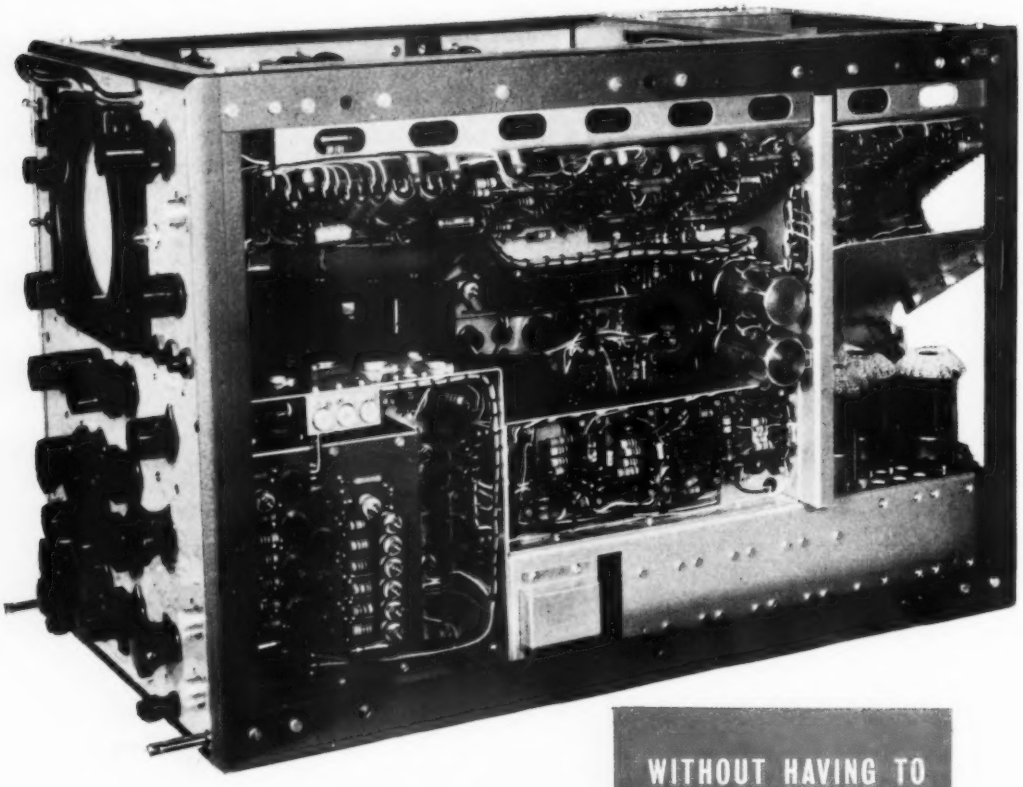


Quality—take the CD 711S.2 *for example*

AD 557	CD 814.2	CD 518/CD 568	CD 513.2
BANDWIDTH: DC to 1 Mc/s.	**BANDWIDTH:** 0.9 c/s to 9 Mc/s to 12 Mc/s (6 db).	**BANDWIDTH:** DC to 5 Mc/s.	**BANDWIDTH:** DC to 10 Mc/s.
MAX. SENSITIVITY: 3 mV/centimetre.	**MAX. SENSITIVITY:** 40 mV/centimetre. Constant bandwidth.	**MAX. SENSITIVITY:** 0.4 V/centimetre.	**MAX. SENSITIVITY:** 1 mV/centimetre.
SENSITIVITY AT MAX. BANDWIDTH: 30 mV/cm—100 V/cm.	**TIME BASE RANGE:** (inc. expansion) 0.02 μSec/cm— 0.01 Sec/cm.	**SENSITIVITY AT MAX. BANDWIDTH:** 10 V/centimetre.	**SENSITIVITY AT MAX. BANDWIDTH:** 10 V/centimetre.
TIME BASE RANGE: (inc. expansion) 0.1 μSec/cm—1 Sec/cm.	**CALIBRATION ACCURACY:** 5% velocity (marker pips). 5% amplitude. (50 c/s substitution).	**TIME BASE RANGE:** 0.1 μSec/cm—10 mSec/cm.	**TIME BASE RANGE:** (inc. expansion) 0.025 μSec/cm— 0.1 Sec/cm.
CALIBRATION ACCURACY: 10% velocity. 5% amplitude.	Weight only 42 lbs. (20 kg.) 6-centimetre picture at 9 Mc/s. Integral TV sync. separator.	**CALIBRATION ACCURACY:** *CD 518:* 1 μSec and 10 μSec markers, Accuracy 2%. 1 μSec sinusoid, Accuracy 1%. *CD 568:* Sinewaves at 1, 10 and 100 μSec periods, Accuracy 1%. 2% Amplitude (by meter).	**CALIBRATION ACCURACY:** 5% velocity. 5% amplitude.
ADDITIONAL FACILITIES: Power output for ancillaries. Long-persistence tube with flare suppression. Direct access to plates.		0.6 μSec delay line. T.B. delay 0—10 mSec. Designed for field use.	Access to plates. TV sync. input. Socket for power probe.
EDUCATION GENERAL PURPOSE		RADAR and Communications	GENERAL PURPOSE

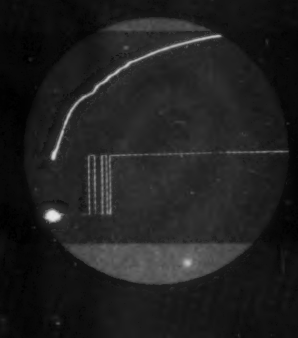
Adopted for use by the British Armed Services and by NATO, the Double-Beam CD 711S.2 is a typical example of Solartron's adherence to precise manufacturing standards. With stability of performance assured by components which meet Spec. DEF 5000, backed by generous yet functional construction, the purchaser of a CD 711S.2—or indeed any Solartron oscilloscope — is assured of a fine investment.

how to capture a transient...



This latest, important addition to the Solartron oscilloscope range represents a significant advance in detailed examination of "once-in-a-lifetime" phenomena. The IPO has already been ordered in quantity for use in United Kingdom Atomic Energy Establishments and is widely recognised as the leading tool for analysis of non-repetitive phenomena. The versatility of the instrument completely eliminates the need for time-wasting photography with all its attendant shortcomings. Using a 'Memotron' tube, the IPO has a writing speed of better than 125,000 cm/Sec., (8 μSec/cm) with an erase time of less than 0.2 Sec. Both 'Y_1' and 'Y_2' channels are DC coupled and have a max. sensitivity of 10 mV/cm., whilst for convenience of X-Y plotting 'X' and 'Y' amplifier sensitivity ranges are identical between 100 mV/cm and 30 V/cm. Time base switching provides seven basic decade ranges from 1 μSec/cm to 10 Sec/cm, each of which may be further sub-divided seven times between x1 and x10. Write for detailed literature.

WITHOUT HAVING TO TRY VERY HARD



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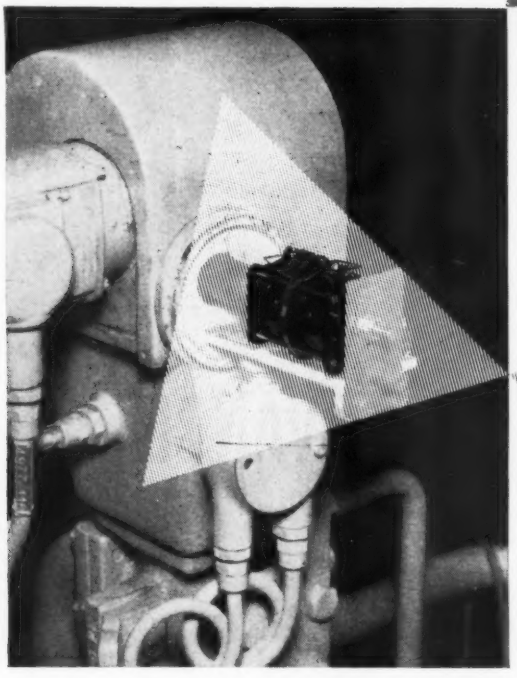
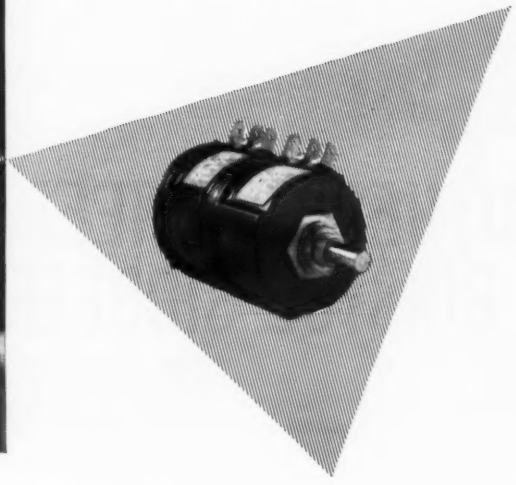


The Rolls-Royce Altitude Test Plant at Derby uses Beckman/Helipot Potentiometers exclusively

for valve position control and generation of control signals.



Above: Series 'C' Helipot, two gang unit, mounted on a large control valve at the Rolls-Royce Altitude Test Plant, Derby. These potentiometers ensure an accurate and fine control of temperature and pressure in the engine test cells, corresponding to the desired altitude conditions.

Helipots provide reliable, long-life operation, embodying 15 years' continuous improvements in design and manufacture.

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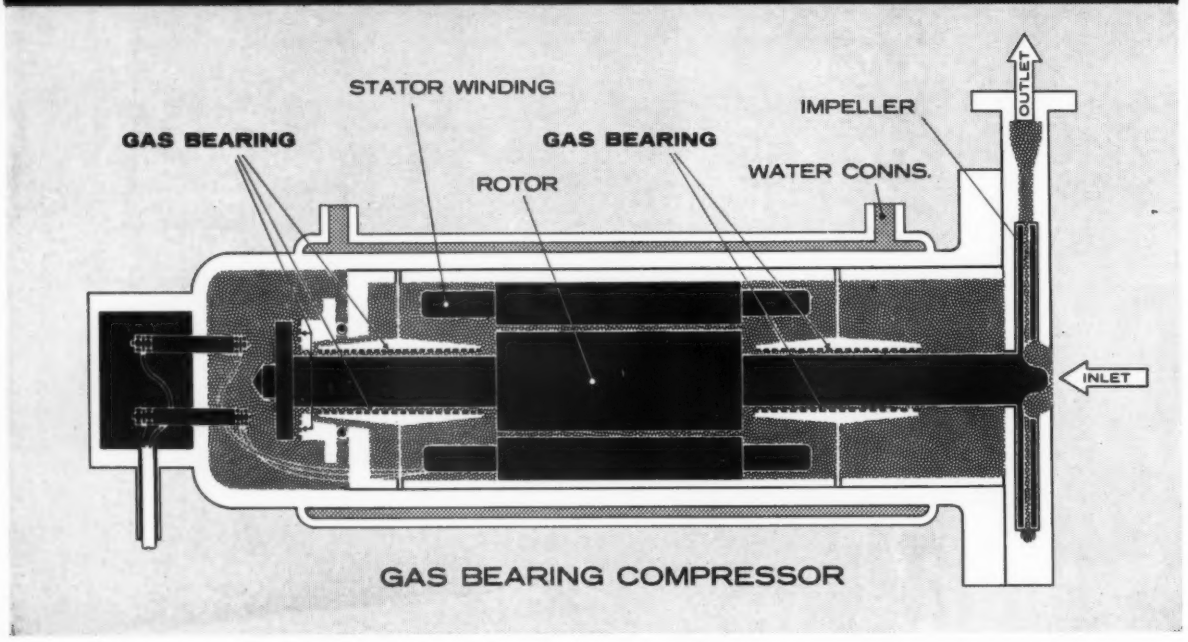

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These Bristol Siddeley compressors have been designed specifically for systems where contamination from lubricants or leakage to atmosphere cannot be tolerated. Each unit, fitted with hydrodynamic-type gas bearings, is totally enclosed and no seals are required between the impeller and the bearings.

Gas bearings have several great advantages over oil lubricated bearings: the load-carrying capacity increases with speed, temperature and pressure; the bearings are supported on a film of the gas which is being circulated in the system, so there is no metal-to-metal contact under operating conditions and wear and maintenance are reduced to an absolute minimum; perfect cleanliness is preserved at all times.

Applications

Bristol Siddeley gas bearings were developed originally to meet the extremely fine limits of operating purity and precision of manufacture demanded by the advent of nuclear engineering. But gas bearings have many other applications where a rotating shaft must be supported in such a way that no contamination and leakage can be allowed and where the supply of chemically pure fluids or gases is essential: in the textile, chemical engineering, pharmaceutical, food storage and processing industries, to name but a few.

For further information about Bristol Siddeley gas bearing compressors and gas bearings, please write to H. J. Prince, Sales Manager, Reactor Components Division, Bristol Siddeley Engines Limited, P.O. Box 17, Coventry, England.

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Weight - for - weight, NEWTHERM compares favourably with many materials far inferior in thermal efficiency and strength. This light weight is evidenced in the handleability of NEWTHERM, which even in the largest sections can easily be carried in one hand.

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Supplied in pre-formed sections and slabs, NEWTHERM is available in a wide range of standard sizes (and also as plastic). The smooth surface and straight edges permit easy and speedy fitting, with minimum joints and neat finish.

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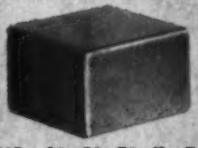

1480B 8"×5"×7" £2 7 6

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new small and miniature standard cases at really *LOW PRICES!*

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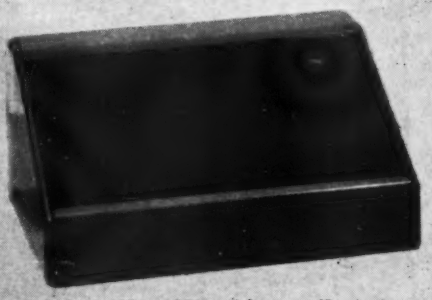

1450B 10½"×19" Panel Size £5 4 0

1410C 7" ×19" Panel Size £3 12 8

1450A 10½"×12" Panel Size £3 18 10

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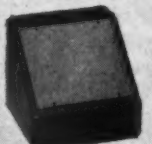

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These new cases have been designed as a result of the fast development in miniaturisation of electronics and electrical instruments. The cases are of two types: with sloping front panels, and rectangular cases with vertical front panels. Both types are available in standard duo-tone finishes. Imhofs have also produced a new type chassis incorporating fixing brackets especially for these new cases

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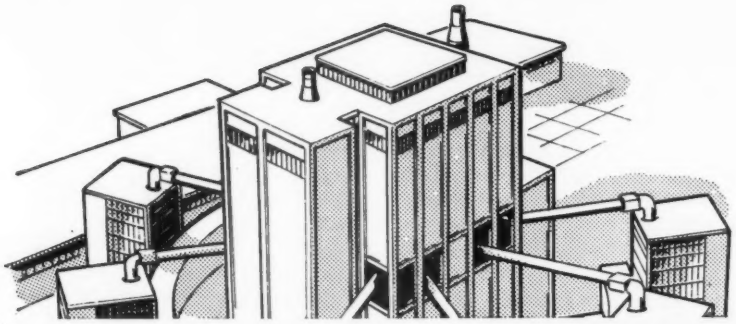
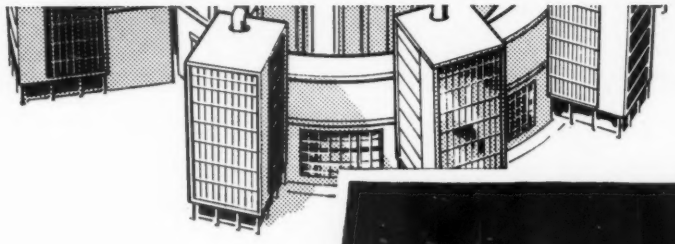
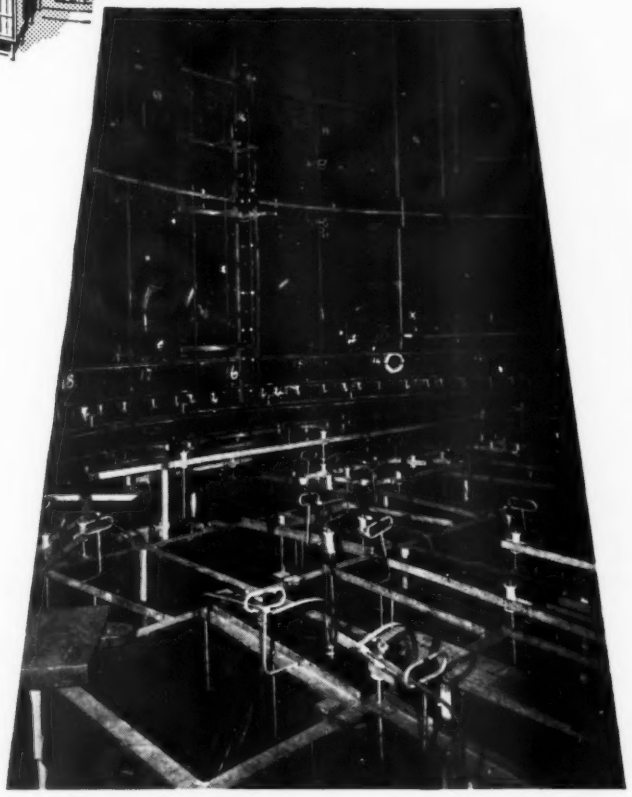
U.S.A. *Bud Radio Inc, Cleveland 3, Ohio*
BRIT. GUIANA *Davsons Caribbean Agencies Ltd, Georgetown*



EFCO 'KNOW-HOW' AT BERKELEY.....



Reactor pressure vessel stress relieving installation planned, erected and supervised by EFCO



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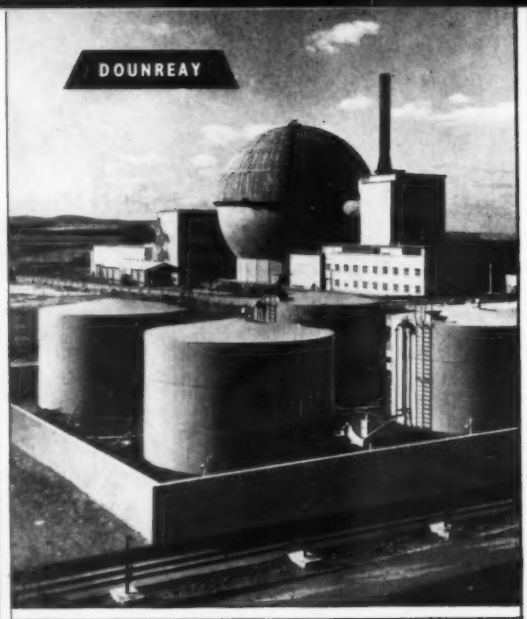
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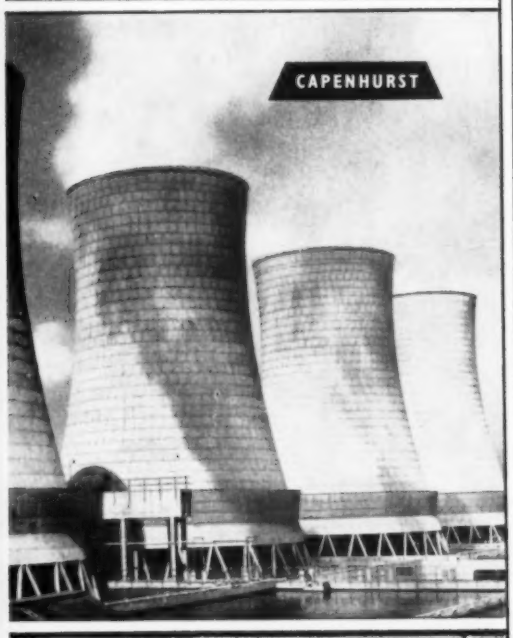
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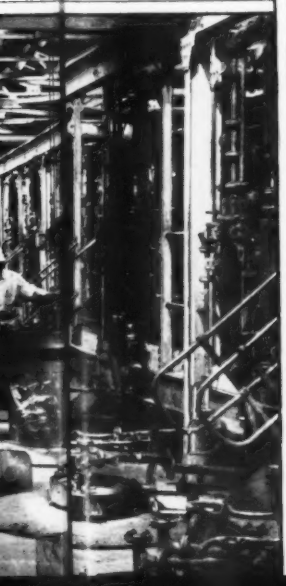

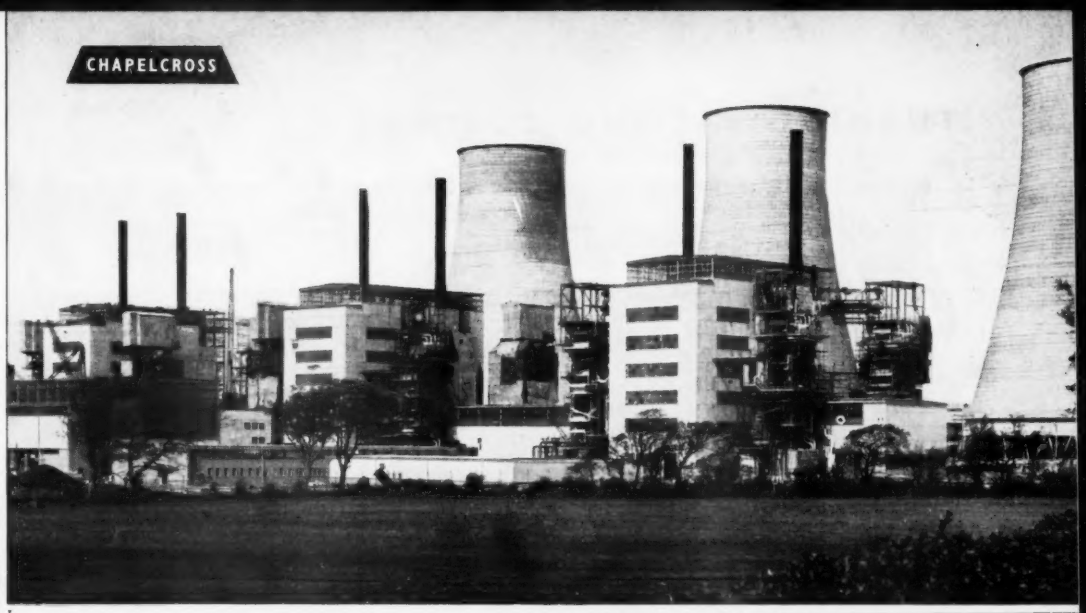

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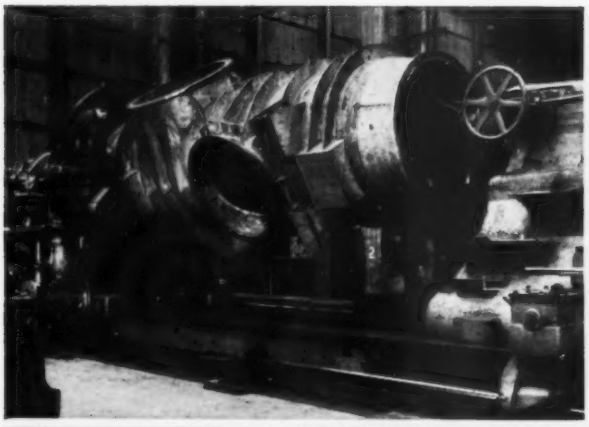

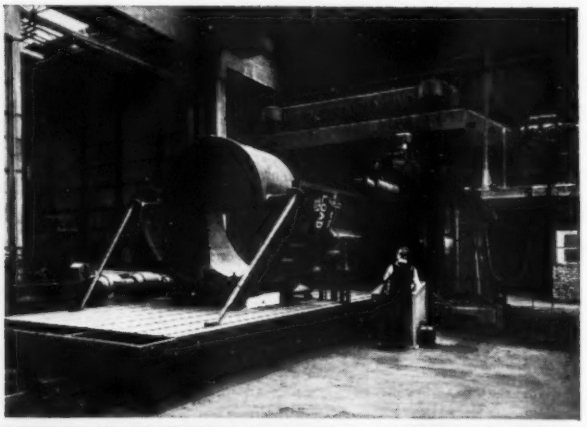

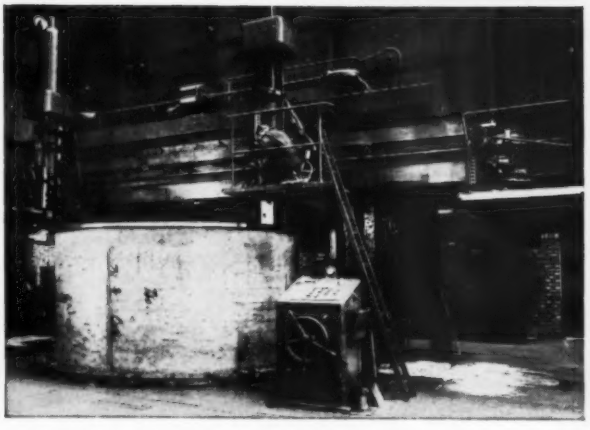

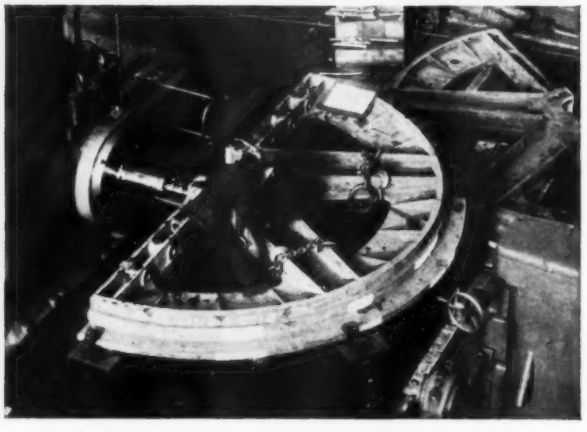

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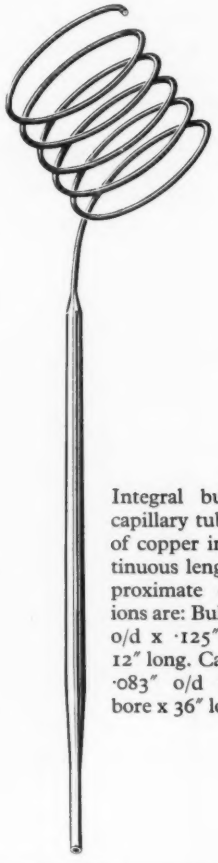

Integral bulb and capillary tube made of copper in a continuous length. Approximate dimensions are: Bulb–·208″ o/d x ·125″ bore x 12″ long. Capillary–·083″ o/d x ·020″ bore x 36″ long.

Designers have a habit of asking for the impossible, but in a surprising number of cases Accles & Pollock produce an answer that enables the production people to translate the concept on the drawing-board into a physical, functional form. Accles & Pollock welcome all such opportunities to co-operate in developing new applications in the form of tubes and tubular sections.

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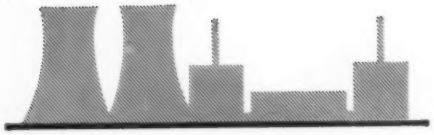

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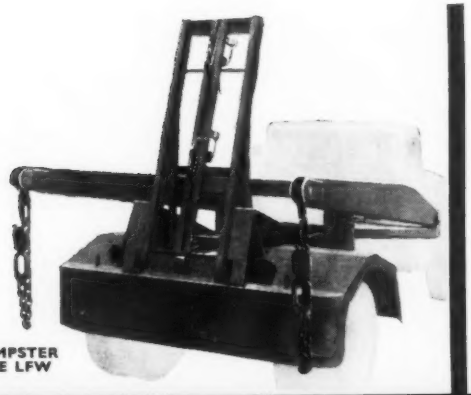

DUMPSTER TYPE LFW

TILT TYPES

Illustrated above is the type LFW. The assembly with hydraulic operation is mounted on a standard chassis. This will handle tilt type and drop bottom containers. The illustrations below feature the type GRD which again handles both tilt type and drop bottom containers with a fork lift specifically designed for high dumping.

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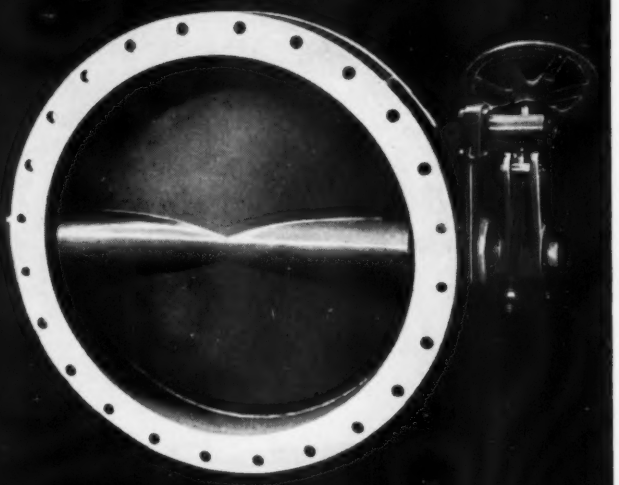

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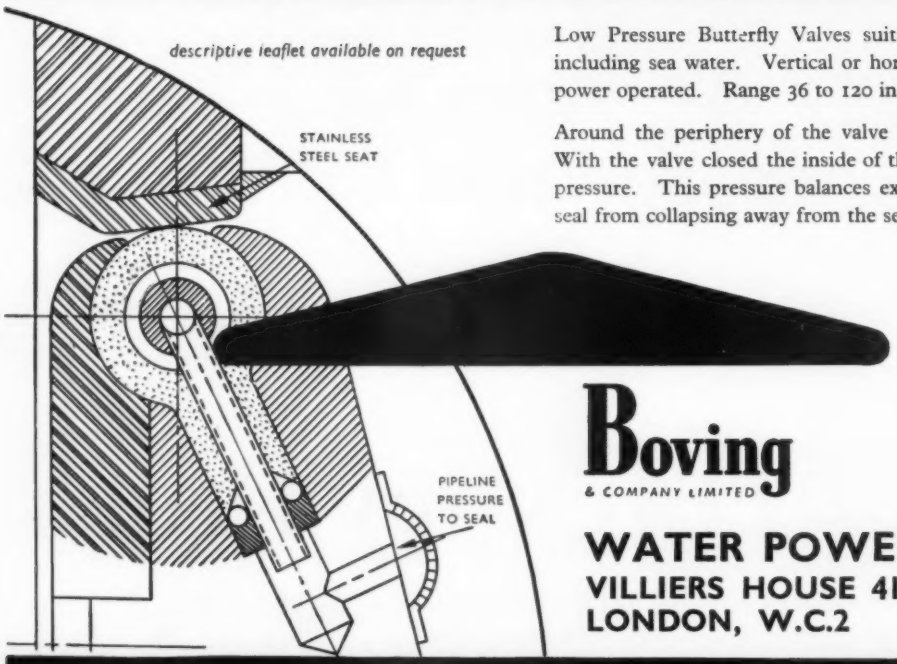

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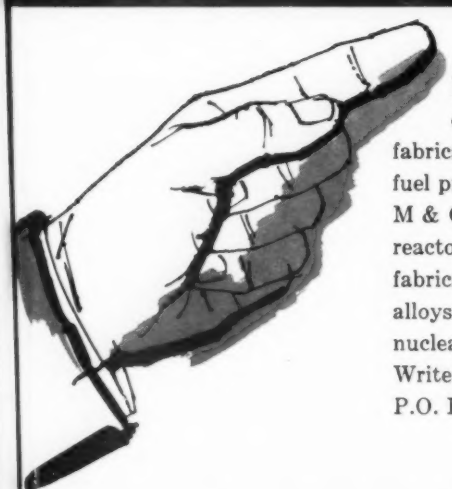
P1554

CERMET FUEL PRODUCTION E

Shape	No. of elements	MATERIALS			LOADING PER ELEMENT		CORE			
		Uranium process	Stainless-Steel Type		UO_2 (gm)	Wt. %	Length (in.)	Width and camber (in. ± mils)	Thickness (mils)	End cl (in. ±
			Matrix	Cladding						
Plate	1,305	Hi-fired	304	304	49.2±0.1†	30†	36±0.5	2.322±125	15±2	0.50±
Wire	155 pcs; 20,000 ft.	Hi-fired	310	304	338±0.1	35	1008±15	—	97±3	0.75
Plate	1824	Hi-fired	304	304	20.5±0.1	18.8	36±0.5	—	20±1	0.25
Plate	384	Hi-fired	304	304	16.9±0.1	19.7	35±0.5	—	20±1	0.25
Plate	206	Hi-fired	304	304	15.8±0.1	18.6	36±0.5	—	20±1	0.19
Plate	206	Hi-fired	304	304	15.8±0.1	18.6	35.5±0.5	—	20±1	0.19
Plate	25	Hi-fired	316	318	46.1±0.1	30	28±1	1.215±25	33±1	0.75
Plate	25	Hi-fired	316	318	35.4±0.1	30	28±1	0.920±25	33±1	0.75
Plate	25	Hi-fired	316	318	27.9±0.1	30	28±1	0.744±25	33±1	0.75
Plate	25	Hi-fired	316	318	18.15±0.1	30	28±1	0.465±25	33±1	0.75
Plate	300	Hydro-grown	316	318	46.1±0.1	30	28±1	1.215±25	33±1	0.75
Plate	300	Hydro-grown	316	318	35.4±0.1	30	28±1	0.920±25	33±1	0.75
Plate	300	Hydro-grown	316	318	27.9±0.1	30	28±1	0.744±25	33±1	0.75
Plate	300	Hydro-grown	316	318	18.15±0.1	30	28±1	0.465±25	33±1	0.75
Plate	25	Hi-fired Spherical	316	318	46.1±0.1	30	28±1	1.215±25	33±1	0.75
Tube	430	Hi-fired	304L	304L	60.4±0.6	19.5	70.5±0.75	—	16±1	2.0±
Tube	430	Hi-fired	304L	304L	38.0±0.4	19.5	70.5±0.75	—	16±1	2.0±



This Chart outlines the cermet UO_2-stainless stee experience available to you at M & C Nuclear. Work c fabrication processes to produce quantities of high quality fu fuel program of these advances by consulting M & C Nuclea M & C Nuclear also produces uranium-oxide: aluminum fue reactors. In addition to cermet, ceramic and alloy fuel assem fabricates uranium, thorium, zirconium, aluminum, hafnium alloys and oxides, and other materials into wire, rod, tube, c nuclear experiments.

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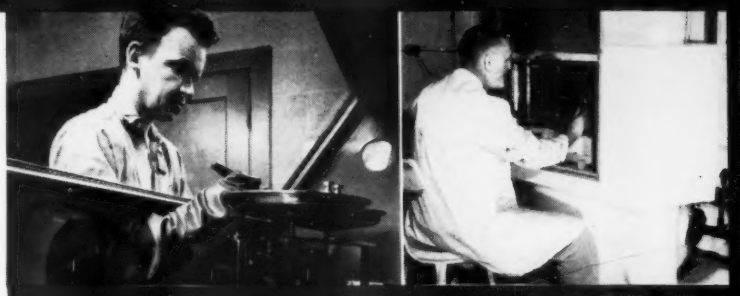
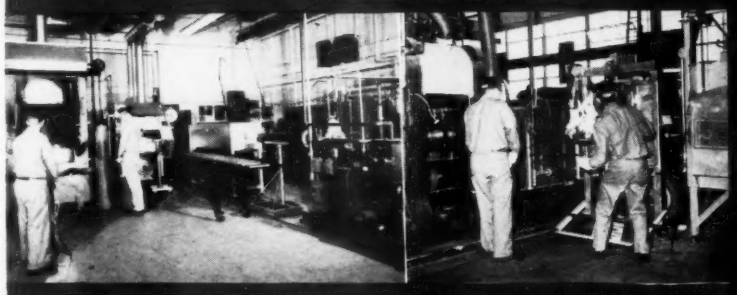
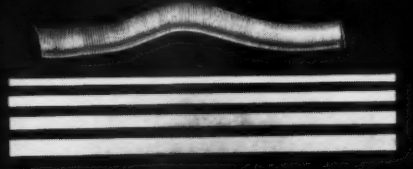
FUEL ELEMENTS • CORE COMPONENTS

N EXPERIENCE

ckness mils)	CLAD			ELEMENT		
	End closure (in. ± mils)	Edge closure (mils)	Surface (mils)	Length (in. ± mils)	Width (in. ± mils)	Thickness (mils)
5±2	0.50±250	312.5±62.5	5±2	37.000±250	2.9475±2.5	25±1
7±3	0.75 min.	–	14±4	min 1088	–	125±1
0±1	0.25 min.	145±55	5±1	36.995±15	1.431±3	30±1
20±1	0.25 min.	145±55	5±1	36.995±15	1.196±3	30±1
20±1	0.195±70*	145±55	5±1	36.995±15	1.196±3	30±1
20±1	0.195±70*	145±55	5±1	36.495±15	1.196±3	30±1
3±1	0.75±20*	20 min	6±1	31.600±10	1.311±1	45±1
3±1	0.75±20*	20 min	6±1	31.600±10	1.017±1	45±1
3±1	0.75±20*	20 min	6±1	31.600±10	0.830±1	45±1
3±1	0.75±20*	20 min	6±1	31.600±10	0.556±1	45±1
3±1	0.75±20*	20 min	6±1	31.600±10	1.311±1	45±1
3±1	0.75±20*	20 min	6±1	31.600±10	1.017±1	45±1
3±1	0.75±20*	20 min	6±1	31.600±10	0.830±1	45±1
3±1	0.75±20*	20 min	6±1	31.600±10	0.556±1	45±1
3±1	0.75±20*	20 min	6±1	31.600±10	1.311±1	45±1
16±1	2.0±375	–	16±1	76.000±31	0.720^{+3}_{0} o.d.	48±1
16±1	2.0±375	–	16±1	76.000±31	0.688^{+3}_{0} o.d.	48±1







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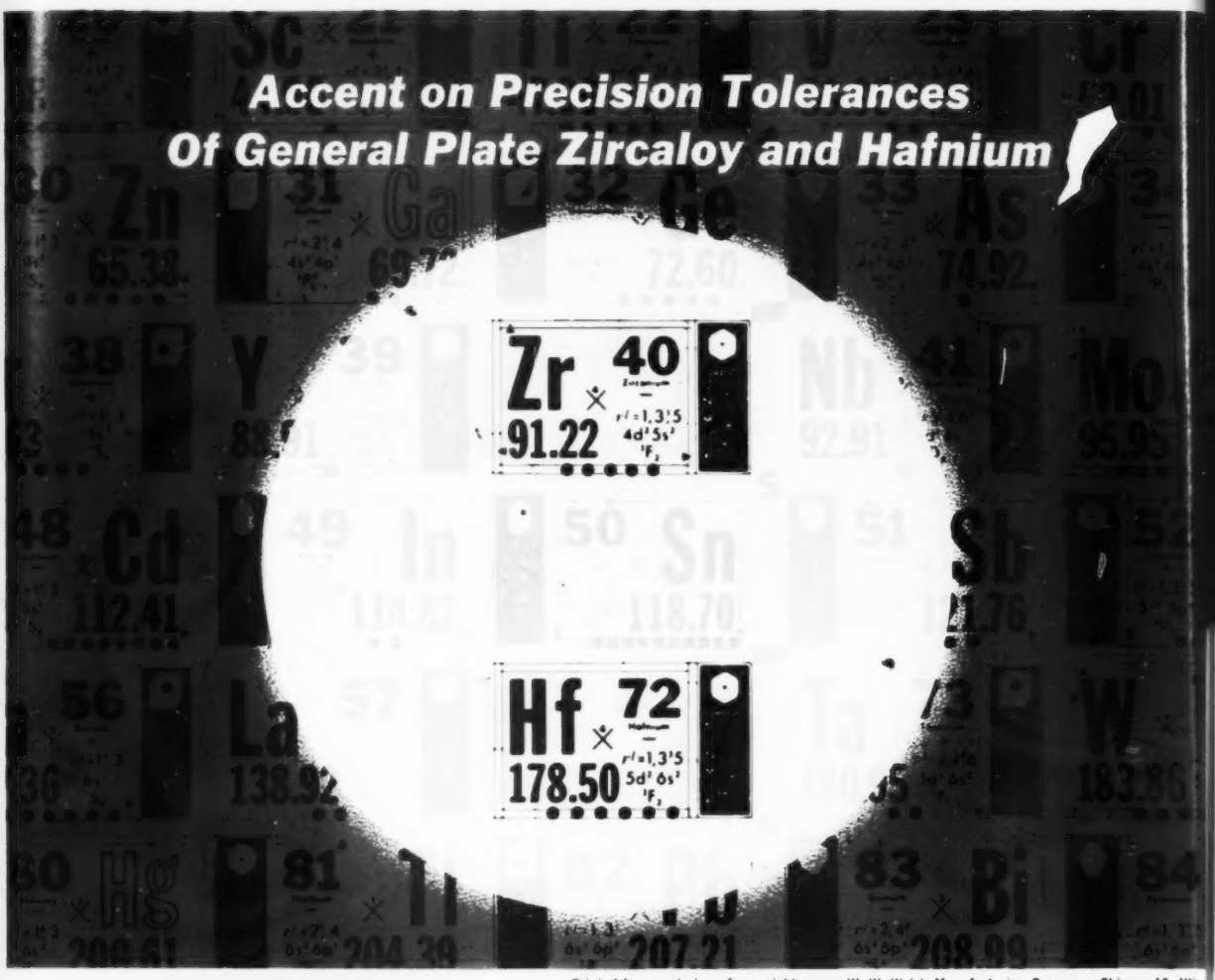

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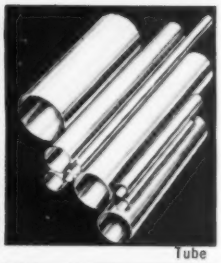
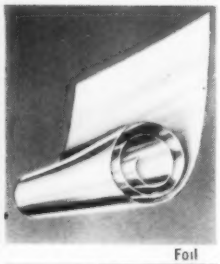
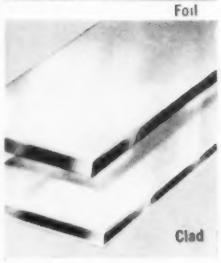

Tube

Wire


Foil

Strip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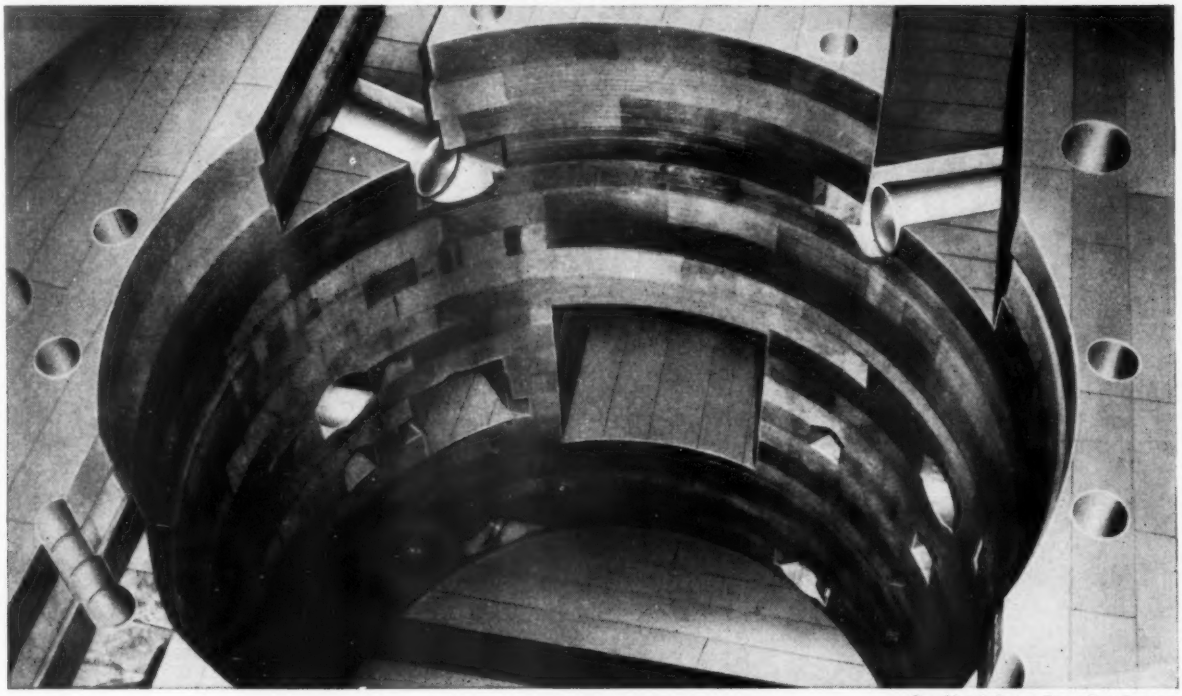

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Properties of UNION CARBIDE Nuclear Graphite

	AGOT Graphite	TSF Graphite
Atomic Weight	12.011	12.011
Density g/cm³	1.70	1.70
Microscopic absorption cross section (millibarns)*	4.50	3.95
Microscopic scattering cross section (barns)	5.09	5.09
Macroscopic absorption cross section ($cm^{-1} \times 10^{-5}$)	38.30	33.67
Macroscopic scattering cross section (cm^{-1})	0.432	0.432
Average logarithmic energy decrement per collision	0.158	0.158
SLOWING DOWN POWER	0.0684	0.0684
MODERATING RATIO	177.5	203
REFLECTING RATIO	1125	1285
DIFFUSION LENGTH	49	52

*at 2200 meters/sec.

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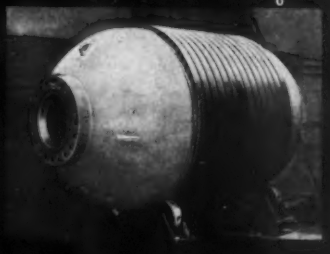

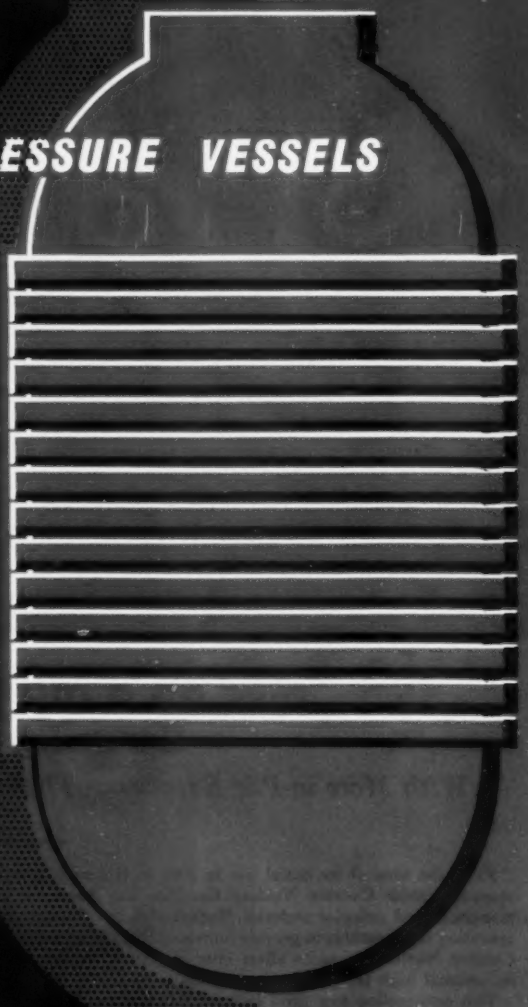

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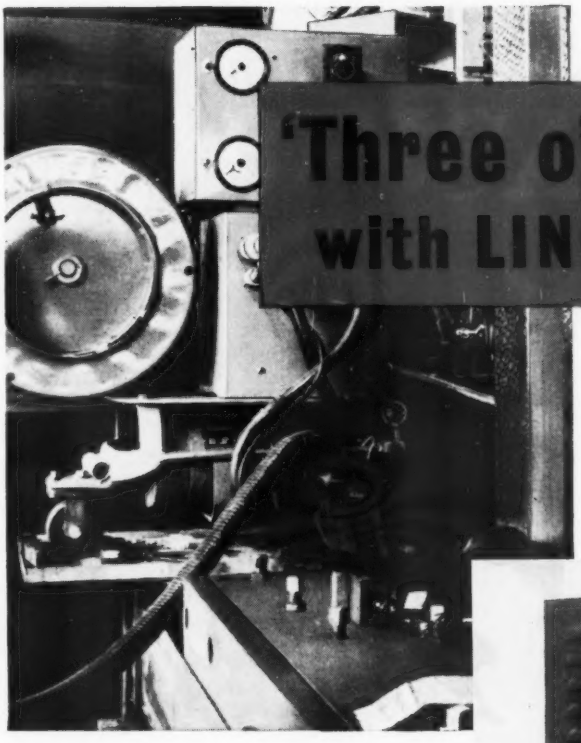
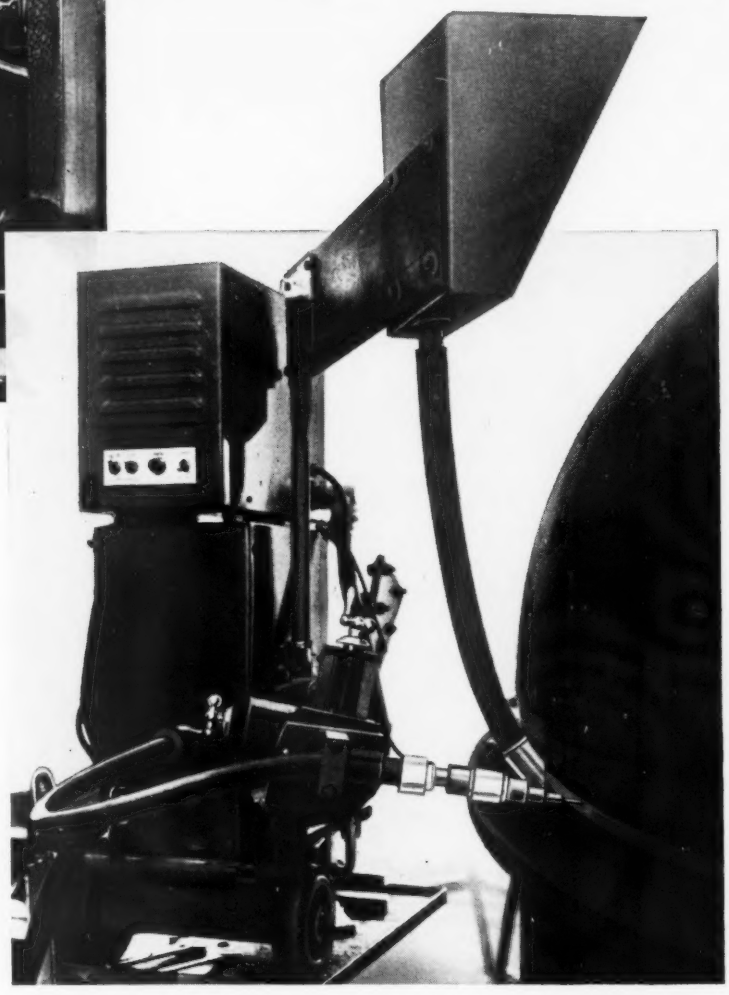


'Three o'clock' welding with LINCOLNWELD



THE LINCOLNWELD Universal Tractor in action at the Derby works of International Combustion Co. Ltd. The illustrations show the Universal Tractor automatically welding in the '3 o'clock' position, a section of one of 4 heat exchangers for The Advanced Gas Cooled Reactor, being built at Windscale, Cumberland, for the United Kingdom Atomic Energy Authority. (Photographs by the courtesy of International Combustion Co. Ltd. and U.K.A.E.A.)

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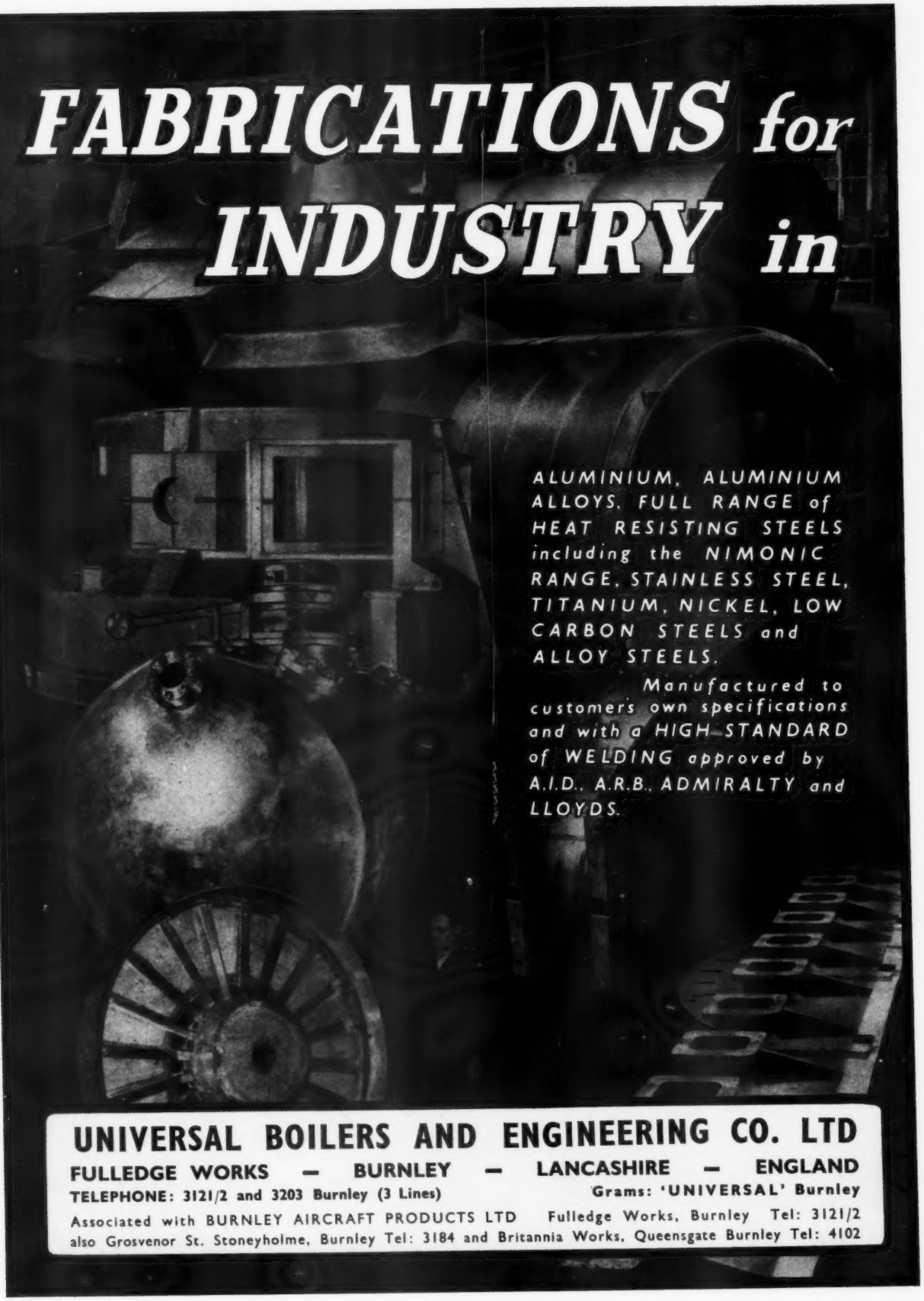
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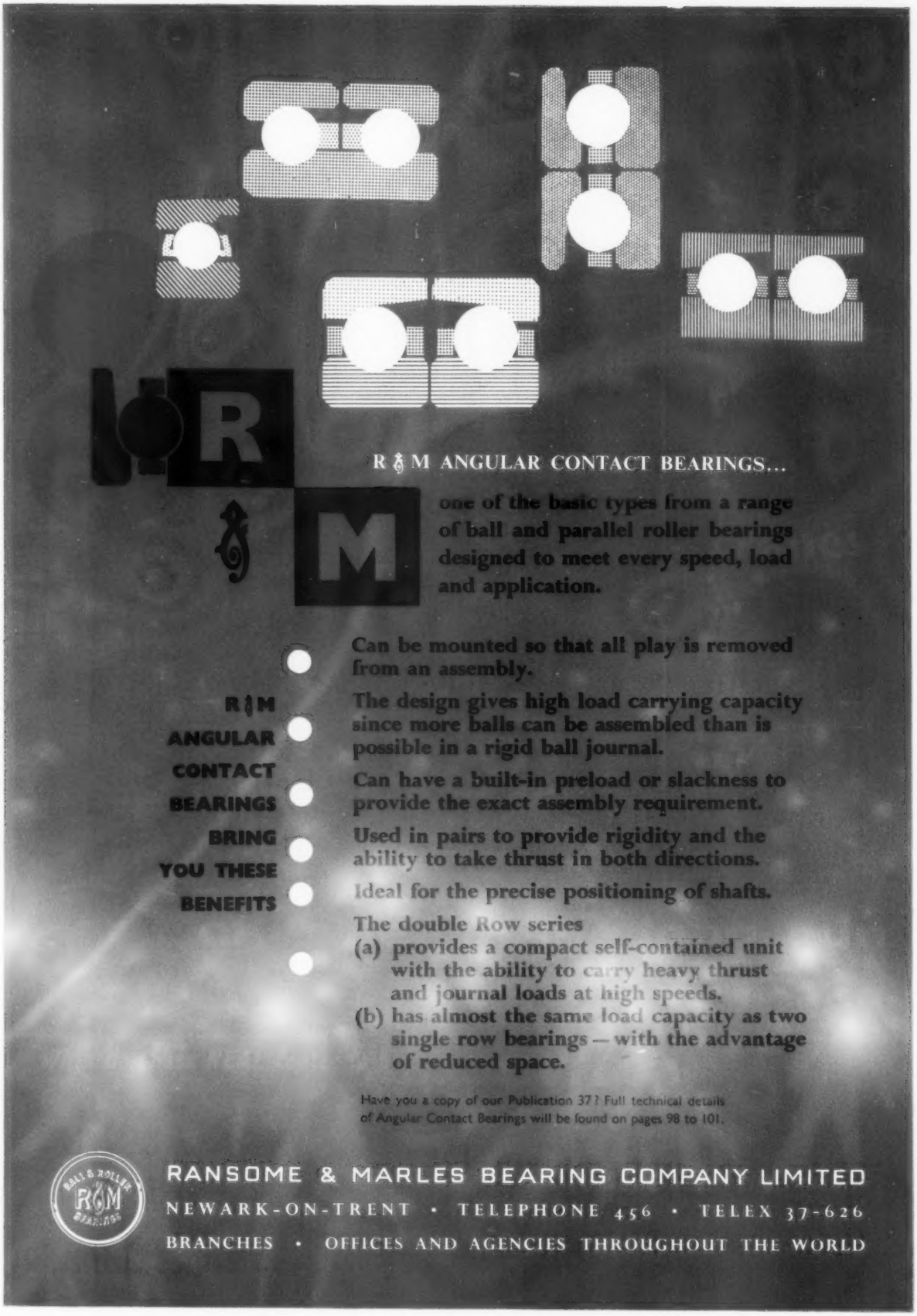
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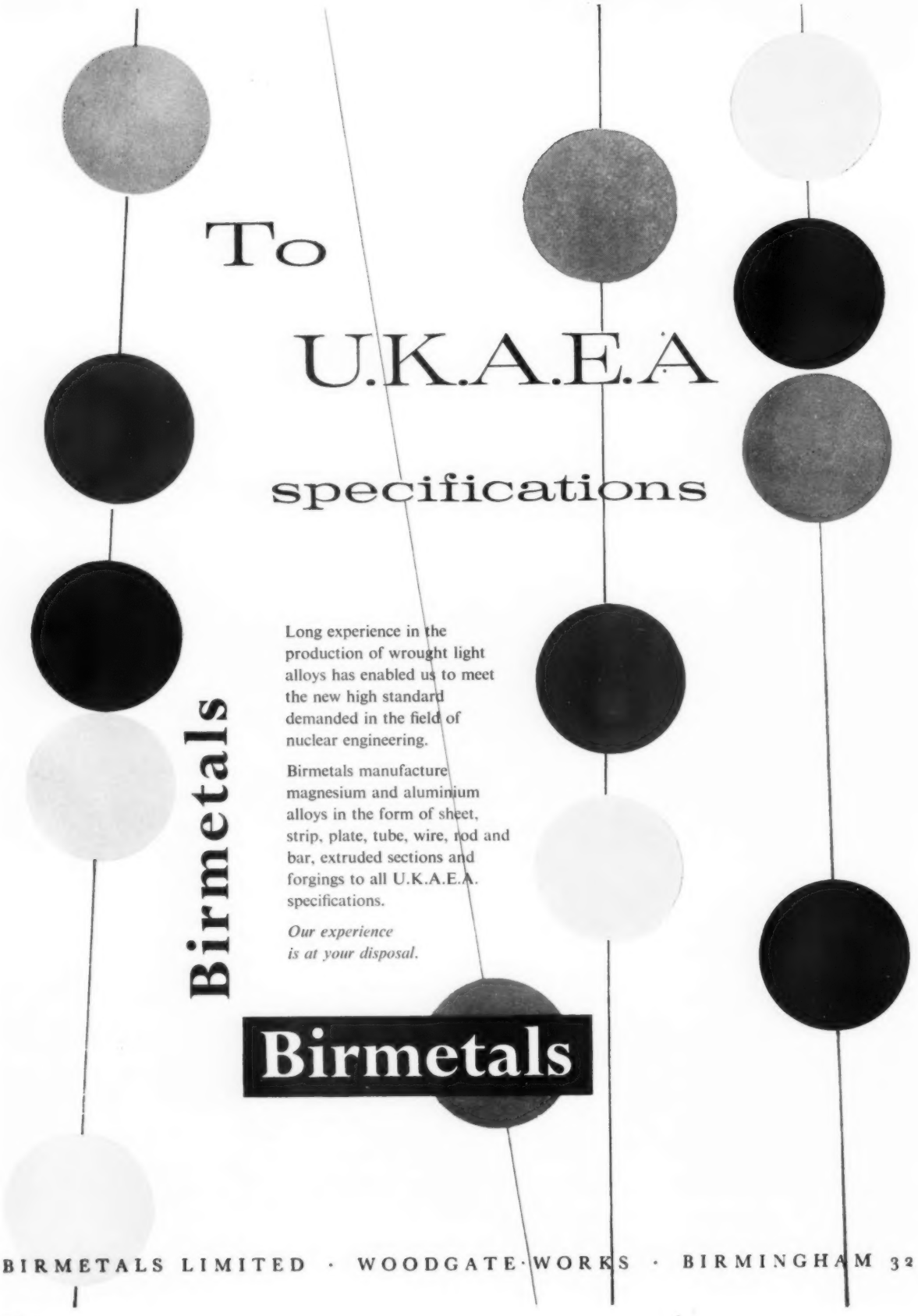

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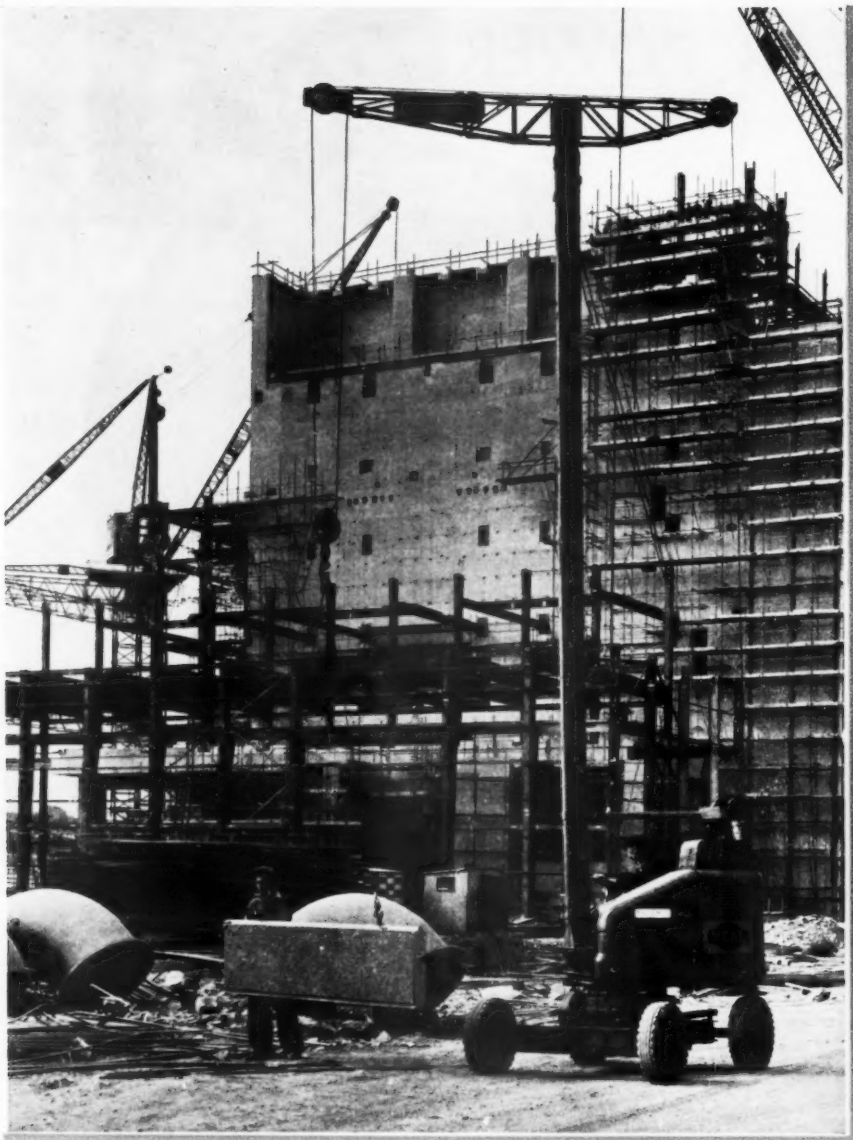

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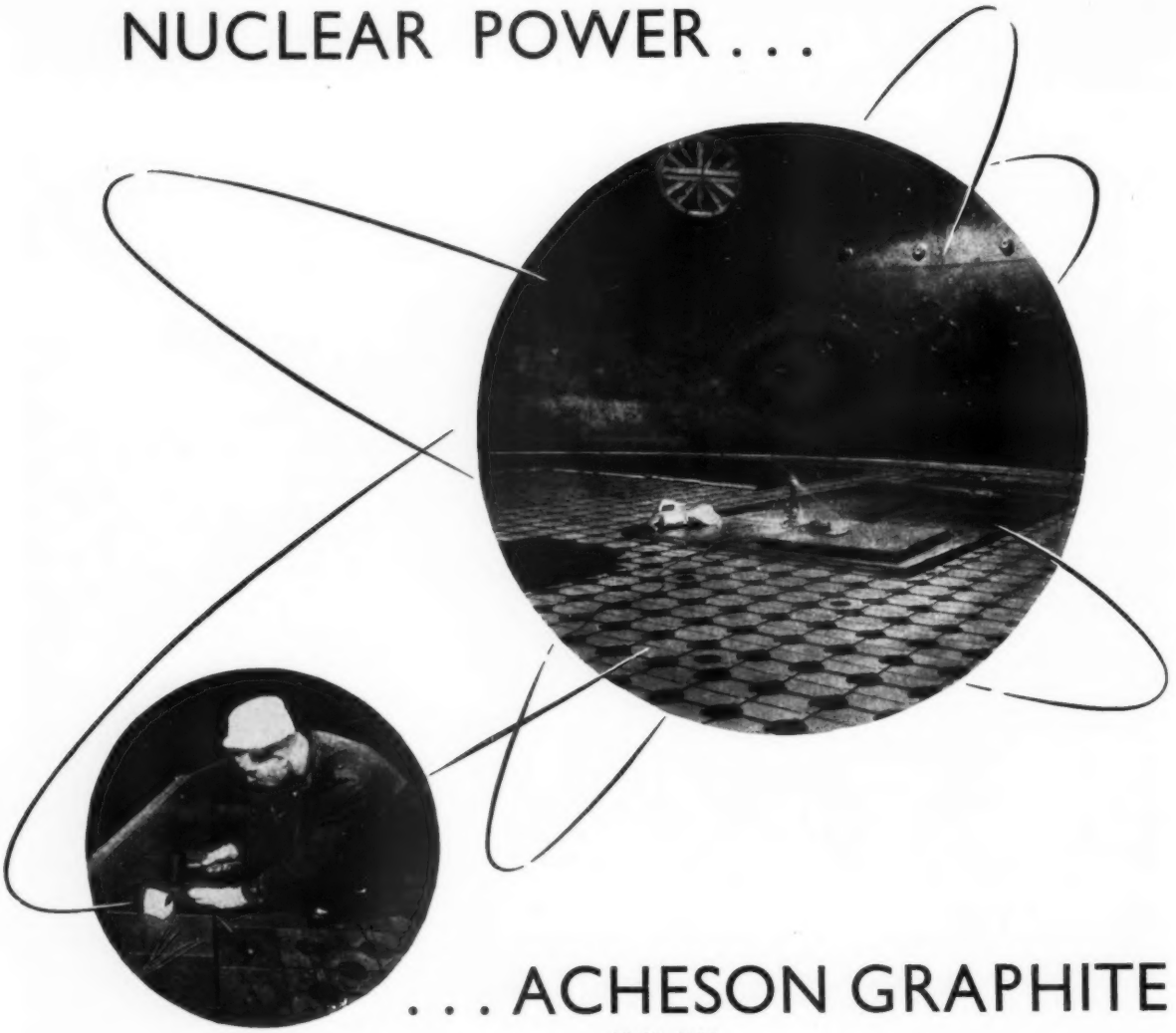

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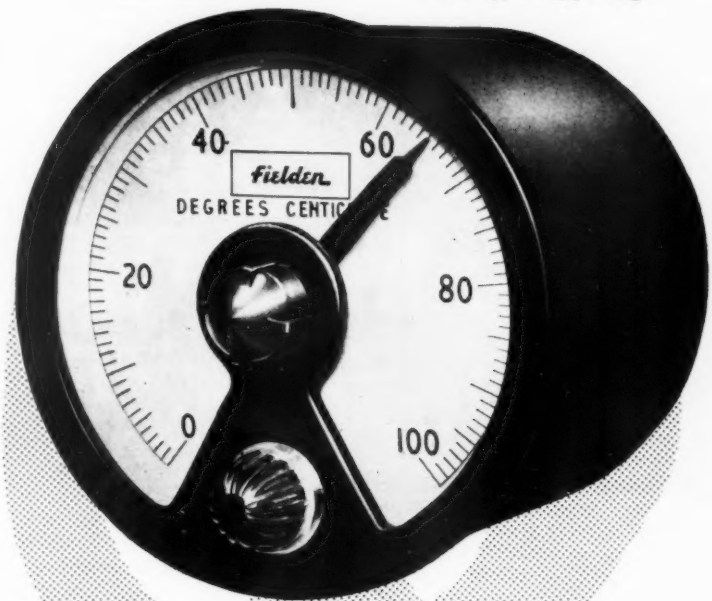

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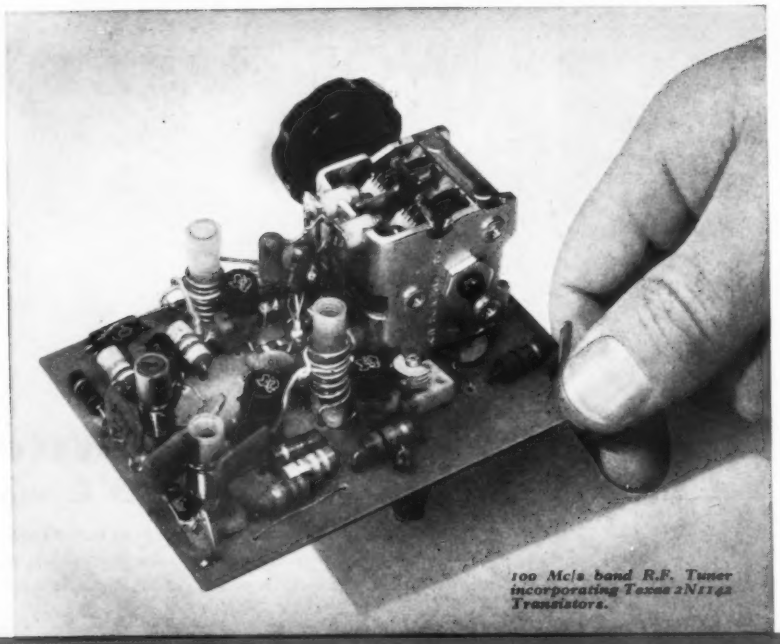

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Nuclear Power
REACTORS MATERIALS INSTRUMENTATION PROCESSES IRRADIATION
JANUARY 1960 VOLUME 5 NUMBER 45

VIEWPOINTS *letters to the Editor*

Bouquet for NP

SIR: Congratulations on your scoop in the December issue with Phillips' article. Some signs of last-minute editorial panic in the page numbering, but what a difference from the six months wait for news after Calder No. 1 went critical!

Kennedy & Donkin, ROBIN P. W. GUARD
12 Caxton St.,
London, W1

A blow for badges

SIR: I should like to comment on the argument Mr. Blair advances (*Viewpoints,* December) in favour of dosemeters rather than film badges and to point out some of the disadvantages of the instruments.

1. Mr. Blair's first point is that the dose to the operator can be read at any moment. This is not true unless operators are exposed in a high radiation field which is most undesirable and, I hope, not common practice in industrial radiography. On the most sensitive quartz fibre electrometer presently available (0–0·2 r), one hour's exposure at the rate of 7·5 mr/h represents a needle movement of only 3·75% of a scale about 0·5 in. (1·27 cm) in length, in other words a needle movement of about 0·02 in. (0·05 cm). Minute to minute reading as implied must of necessity be uselessly inaccurate.

On the other hand, should an operator accidentally receive a relatively large dose (and this is not as uncommon as it should be), it is possible that his dosemeter will be off scale and all direct evidence of the actual dose received is lost—a point of extreme importance from the medico/legal aspect should any subsequent claims for injury or ill health arise. This is a point which must be given careful and deliberate consideration in view of forthcoming legislation.

Surely the logical and safe method of controlling exposure is by the use of battery-operated doserate monitors to establish conditions and ensure working levels are acceptable and to equip personnel with film badges. Pocket electrometers can fill a useful, but supplementary function under these circumstances, but to rely on them as a first or last line of defence is completely unacceptable, especially in view of their shortcomings.

2. The second point, on the confidence and sense of security of operators, implies a possibility of an overdose. This surely puts the cart before the horse. The system of exposing or transferring isotopes or the energizing of an X-ray tube on a routine basis should be so established, designed, and controlled that overdoses are impossible providing a recognized drill is followed. The operators sense of security then follows automatically. In my fairly wide experience no lack of confidence in a film badge system supplemented with monitoring surveys has ever been expressed. As stated previously, however, the wearing of dosemeters supplementary to films is only common prudence when conditions are largely unknown or when entering an area of high radiation for emergency repair work.

3. Some of the disadvantages of quartz fibre electrometers are:—

a. No 'automatic' permanent record is produced as with a film badge.

b. Possibility exists of false readings (high or low) as a result of knocking or dropping the instrument.

c. Instruments are largely insensitive to beta radiation: that from a Co-60 source for instance can be not inconsiderable.

d. Absolute dependence upon the human element (which varies significantly from person to person) is necessary in the conscientious recharging, zeroing, reading and recording of results. All that is necessary with a film badge is to ensure that it is worn and changed at predetermined intervals. This assumes that the film processing and assessing system is dependable and this of course is a prerequisite.

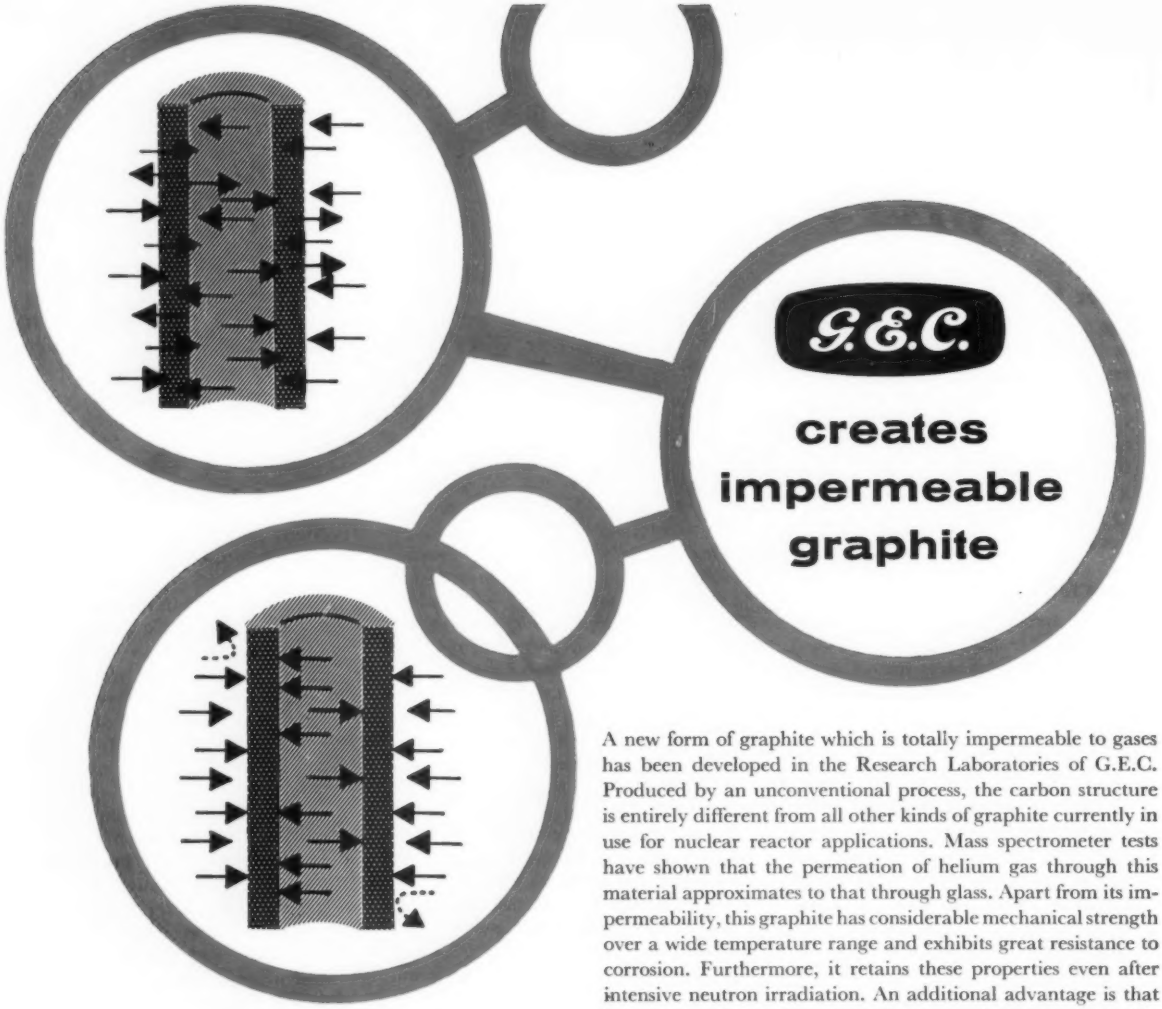
e. Initial cost is high (£10) and due to the nature of construction the instruments are somewhat delicate. The initial cost of one instrument can be expected to cover the cost of film badges, changed on a weekly basis, for one person for two years at least.

In conclusion I would say that I should be extremely sceptical of any radiation exposing records based on this system of personnel monitoring.

Senior Health Physicist, D. J. MATHIAS
Atomic Energy Division,
General Electric Co. Ltd.

DOUNREAY SCOOP

Many of the readers who have written to congratulate NUCLEAR POWER on its Dounreay scoop have expressed amazement at the speed of the whole thing. How, they ask, did we manage to come out with a fourteen page section on the fast reactor, including a first-hand account of the commissioning, five days after it first started up, especially since the project was eighteen months behind schedule, and no one could be certain when it would actually go into operation. The explanation is really quite simple. An article on the instrumentation had been commissioned some months before, and after doing a bit of crystal gazing, the Editor decided to run it in the December issue. Meanwhile, the Works Manager at Dounreay worked on an article describing the final stages of commissioning, keeping it up-to-date and clearing it with the Atomic Energy Authority as he went along. By Friday, November 13, the last problems had been overcome and start-up seemed only a matter of hours away. By this time, of course, the magazine contents had been settled—and most of it printed—but such an important story called for emergency measures, so the printing of the last sixteen pages was halted. On the Saturday morning at 11 o'clock, the fast reactor went into operation. The article was completed, flown down to a private airfield near London and was in the hands of NUCLEAR POWER staff by the time the first announcement of the startup was made by the BBC.



A new form of graphite which is totally impermeable to gases has been developed in the Research Laboratories of G.E.C. Produced by an unconventional process, the carbon structure is entirely different from all other kinds of graphite currently in use for nuclear reactor applications. Mass spectrometer tests have shown that the permeation of helium gas through this material approximates to that through glass. Apart from its impermeability, this graphite has considerable mechanical strength over a wide temperature range and exhibits great resistance to corrosion. Furthermore, it retains these properties even after intensive neutron irradiation. An additional advantage is that it has proved possible to produce sound and impermeable graphite-to-graphite and graphite-to-metal welds.

The most important of the many possible nuclear applications of this revolutionary form of graphite is likely to be as a fuel-canning material, where its characteristic properties should permit the use of much higher operating temperatures. This in turn would result in increased fuel ratings, decreased capital costs, and improved efficiencies for nuclear power plants.

G.E.C. has also developed a new method of impregnating normal graphite which can reduce its permeability to less than a millionth of that of ordinary electrode graphite. The sleeves that support the fuel elements for the Hunterston Nuclear Generating Station, made from graphite impregnated in this way, will isolate the main moderator graphite from the coolant gas stream and permit it to be maintained at a temperature such that no significant storage of Wigner energy will occur during the life of the reactor. *Enquiries should be addressed to The G.E.C. Research Laboratories, Wembley, Middlesex.*

COMPARATIVE PERMEABILITY

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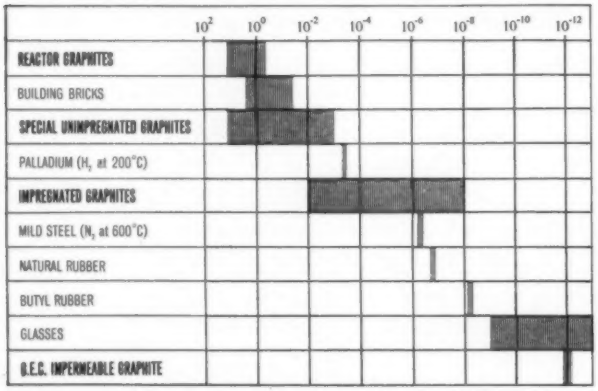

G.E.C. OF ENGLAND

ATOMIC ENERGY DIVISION

327

THE GENERAL ELECTRIC COMPANY LIMITED OF ENGLAND, ERITH, KENT

OPINION

The pace slackens

IT WOULD be easy to think of 1959 as a year of almost unrelieved gloom in the world's atomic energy industries. Many programmes have been revised, and the handful of extra contracts for nuclear power stations has been almost balanced by the number of projects dropped. In the United Kingdom the Central Electricity Generating Board is ordering new stations as slowly as it possibly can without getting irreversibly behind schedule. In Russia the programme has been put back by five years and the rate of building slashed by more than half. The US-Euratom programme, in spite of strenuous efforts by the Agency to prod European countries into action, has got off to a pretty feeble start: instead of the several firm proposals for power reactors expected, only one—SENN in Italy—has materialized and this already existed as a project before the Euratom programme was started. Even in the United States itself, the Atomic Energy Commission's ebullience has given way to a feeling that the palmy days are over and that America cannot continue to investigate every reactor system in sight.

Some good things happened of course. In Britain, Chapelcross went critical so that this country now has an operating nuclear capacity of 368 megawatts. Work on the first round civil stations has fallen slightly behind schedule but without serious incident, and it is as well to remember that this is still the largest constructional programme in the world. The Dounreay fast reactor, though eighteen months behind schedule, did start up in the end.

The construction of the advanced gas-cooled reactor experiment at Windscale continued, while the Atomic Energy Authority took a closer look at beryllium and decided they had better use the reactor to test stainless steel cans as well. In addition they got round to thinking that an insurance against failure of the AGR might be advisable, and picked on the steam-cooled heavy water moderated system.

Several important things did not happen. Serious work on the semi-commercial prototype for a fast breeder reactor power station did not start; nor did construction of the Dragon high temperature reactor, and enthusiasts for the system had the mortification of seeing both the Americans and Germans start work on advanced experiments of their own. The fog round the Government's nuclear fuel policy grew, if anything, thicker still, and on the export side early high hopes were rather blighted by the failure to secure more than one further order.

The reasons behind this world slowdown are partly technological. The complexity and cost of development of atomic power is now more fully appreciated. This is especially true in those lower income countries which thought that cheap atomic power in small units was just around the corner; their views have been modified.

A different frame

In the more heavily industrialized countries the overall fuel situation into which atomic power must be fitted has changed. Fossil fuel costs have stopped rising, and in some cases have actually gone down. This may or may not be a short time phenomenon, but even if coal prices were stimulated by a rise in the general level of economic activity nuclear power stations would still have to face the surprising increase in efficiency and decline of capital cost of conventional plant. However, atomic power's real rival is oil rather than coal, and the price of this is unlikely to go up, as the proportion of known oil reserves to production is increasing. The situation could of course be altered by the present pressure of some governments to limit or tax oil imports; it might be argued that this could only be an artificial boost to atomic power and could easily be cancelled later on but, on the other hand, it might push governments into increasing the heavy capital expenditure which alone can really establish the industry.

All this adds up to a picture which will depress those who had hoped to see the atomic energy programmes keep up their previous progress without a falter, but two facts must be kept in mind. Firstly the early pace was tremendous for a new technology, and even at its reduced rate, even in 1959, the volume of work actually done in this new industry is staggering. Secondly nuclear power stations take years to build, and though the last year has not offered the sight of reactors starting up all over the place, late 1960 and 1961 certainly will. In Britain the year ended on an encouraging note. The 'Galbraith' committee has emerged from its long sleep with a recommendation to invite tenders for a marine propulsion reactor.

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A range developed and perfected by Wakefield-Dick Research

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A Wakefield-Dick research chemist investigating the effects of radiation on lubricants.

Two examples of the NUCLEOL range

NUCLEOL 522 A radiation resistant lubricant based on selected mineral oils of high aromaticity and containing special inhibitors.

NUCLEOL G 120 A grease gelled with a new compound, and specially inhibited. Designed for the lubrication of control actuator bearings operating at the lower radiation levels.

Worldview

the month in atomic energy

Green light for ships

The Minister of Transport, Mr. Ernest Marples, has decided to accept the recommendations of the Galbraith Committee to proceed further with the application of BWRs and OMRs for marine propulsion purposes. The Ministry is issuing invitations to tender for suitable reactors of these types to be installed into a 65,000 ton tanker.

Discussions are being held with shipbuilders and owners regarding participation in the building and operating of this ship.

AEA buys private design

The Hawker Siddeley Nuclear Power Company has received a contract to supply a reactor to the Authority to be installed at Winfrith. To be known as Nestor, Neutron Source Thermal Reactor, it is based on the Jason reactor (see NUCLEAR POWER, March 1959, pp. 90 and 91) and will be in operation by December 1960.

Dr. P. W. Mummery, of AERE, Harwell, told NUCLEAR POWER that Nestor will be used for research on GCR's, AGR's and a liquid moderated system. To meet the Authority's requirements the normal Jason layout has been modified so that the reactor will be capable of continuously operating at a power of up to 10 kW and serving up to five experimental assemblies simultaneously.

The fuel in Nestor will be an alloy of highly enriched uranium and aluminium arranged in an annulus of plates.

UK gives more know-how

At the beginning of December the first meeting of the Ministerial Committee for Cooperation between the UK and Euratom was held. The two most important items discussed were the suggested cooperation on reactor development, fast breeders and AGR systems, and collaboration in fusion research.

A preliminary technical meeting has been proposed for January 1960, when the possibilities of Euratom personnel joining the Authority's reactor projects will be investigated.

Euratom is now to benefit from the AEA's work on fusion research at Harwell and, when it becomes operational, Culham. Already the Community has come to similar arrangements with the French authorities on 'mirror' research and with the Germans for accelerator development. In this way, Euratom is now in a position of learning all there is to learn on nuclear fusion without having to go to the expense of setting up its own research facilities.

Zenith goes critical

On Saturday, December 19, Zenith, the zero energy high temperature reactor, went critical. This GEC-built (see NUCLEAR POWER, August 1959, pp. 90 and 91) unit is the first major facility at the AEA's new establishment at Winfrith to come into service and will operate under temperature conditions similar to those expected in high temperature power reactors. Zenith will be rented to the 20 MW dragon international project to check design calculations. Already over 30 specialists from overseas organizations have joined the Winfrith staff for this work.

INTERNATIONAL

Watching food interests

Rome—A commission of the Food and Agriculture Organization of the United Nations, FAO, has decided to expand, over the next two years, the organization's work in the application of nuclear energy to agriculture and food. This will enable FAO's activities, which have been mainly confined to Europe so far, to be extended to Asia, Latin America, the Near East and Africa.

The principal lines of work will be the coordination of research in the use of irradiation for the preservation of food and studies on the agricultural aspects of radioactive contamination.

EIRE

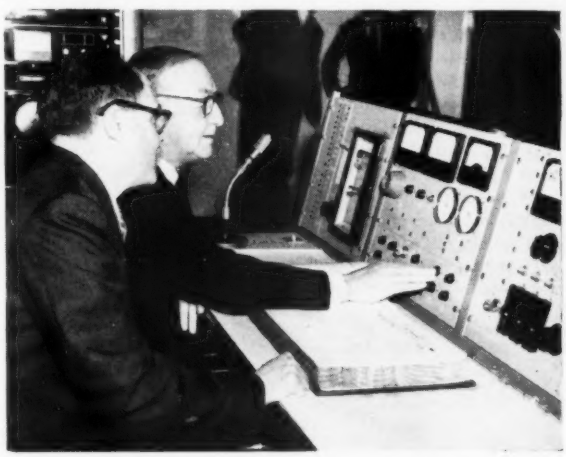
Buying from the US

Dublin—A caesium 137 nuclear irradiator has been ordered by the University here. Using some 700 curies of caesium 137, it will be designed and built by the American company Radiation Applications Inc. When it has been installed, in about four months time, this facility will be used for botanical and genetic research.

ITALY

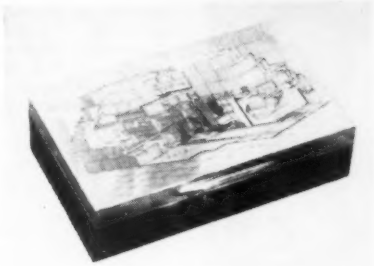
Two reactors start up

Rome—At the end of November two American-built reactors in Italy were brought into service. One is the

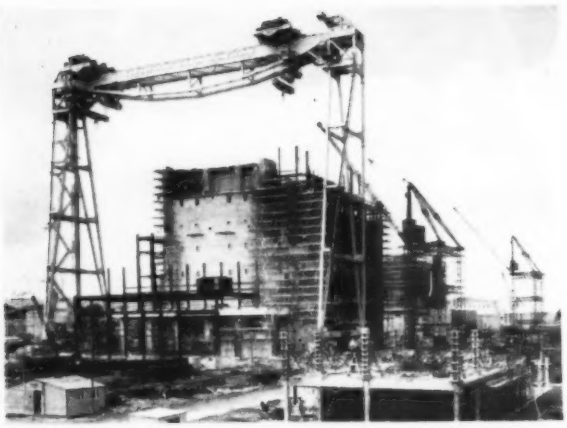


JASON STARTS WORK

Sir John Cockcroft recently inaugurated Hawker Siddeley's reactor at Langley, near Slough. Mr. B. Emmerson, the reactor supervisor, keeps watch



During the opening ceremony Sir Roy Dobson, chairman of Hawker Siddeley presented this 'Jason' cigarette box to Sir John. Within three hours of being started up the first isotope from the reactor was delivered to Slough College of Further Education. The box carries an engraving of NUCLEAR POWER'S drawing of the reactor (March p 91)



HINKLEY POINT
After nearly two years since construction was started the shells of the two reactors have been completed

50 MW aqueous homogeneous research reactor located at the Enrico Fermi Nuclear Study Centre of the Milan Polytechnic Institute and was constructed by Atomics International.

The other, a 1 MW swimming pool reactor, has been installed at Saluggia, some 20 miles north-east of Turin, by the AMF Atomics division. This facility will be operated by the Società Ricerche Impianti Nucleari, SORIN, an organization owned by two Italian industrial groups, Fiats of Turin and Montecatini of Milan. This reactor has a potential capacity of operating at up to 5 MW.

NORWAY

New fuel contract

Oslo—After having had negotiations earlier with the American AEC, the Norwegian Institutt for Atomenergi has ordered the second fuel charge for the OEEC Halden BHWR from A/B Atomenergi of Sweden. This contract is valued at approximately £180,000.

Since the Halden reactor (see *Worldview*, November last) went critical it has been operating at zero power but it is now proposed to add a number of slightly enriched uranium 'spikes'. These, it is anticipated, will enable a power level of 5 MWt to be attained.

The second charge, totalling approximately 3300 lb of 1·5% enriched uranium oxide, will be made up into 100 seven-element assemblies of Zircaloy-clad rods. When delivered in March 1961, it is expected that power levels of up to 20 MWt will be obtained.

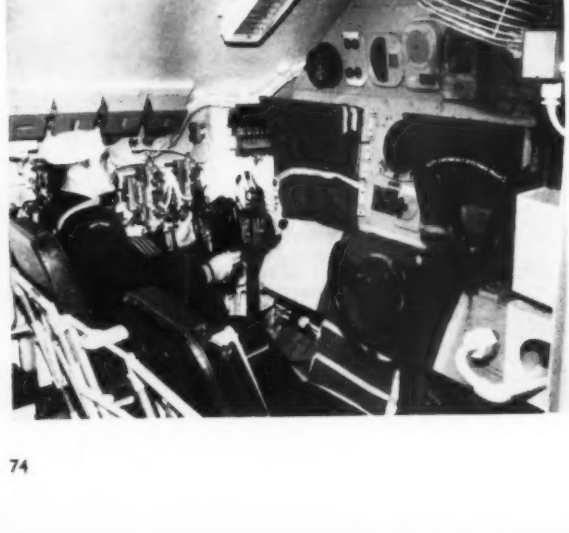
JAPAN

Transfer of responsibility ?

Tokyo—At the beginning of December the Director General of the IAEA, Mr. Sterling Cole, and senior officials of the agency made an extensive tour of Japanese facilities. During discussions covering all aspects of nuclear activities, Japan's wish to place the administration of her bilateral agreements with Canada, the United Kingdom and the United States under the control of the IAEA were reviewed and the possibilities of further cooperation were explored.

WORLDBRIEFS

• **International** A European-American Nuclear Data Committee, of thirteen experts, has been set up by the European Nuclear Energy Agency, in agreement with Euratom, Canada and the United States, to assure collaboration among OEEC member and associate countries in the measurement of nuclear properties.

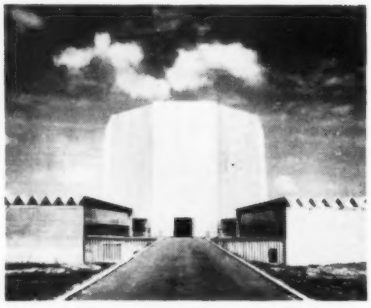


US Navy 'TRITON'
The diving controls of the largest American nuclear submarine. The 447 ft 'Triton' has a cruising range of 110,000 miles

• **International** The twelve Socialist countries forming the Joint Nuclear Research Institute have recently signed a new protocol in Dubna, near Moscow. This provides for a further extension of cooperation and to increase the use of nuclear energy.

• **International** A panel of experts was convened last month by the IAEA to recommend detailed measures for a worldwide project to measure tritium, hydrogen-3, concentrations in water.

• **International** The help of experts and financial contributions are being provided by the IAEA for the training of students in Latin America and South East Asia in the use of radioisotopes.



FIRST PRIVATE ITALIAN REACTOR
The 1 MW swimming pool reactor operated by SORIN has recently gone critical

• **Euratom** Discussions have recently taken place on the participation of Euratom at the German nuclear research centre at Karlsruhe on the study of transuranic elements. Both the Community officials and the Federal authorities stressed that an impetus must be given to the work being carried out in this field of research.

• **Canada–USA** The AEC have informed the Canadian Authorities that it is not in a position to exercise its option to purchase additional Canadian uranium concentrate in the post-1962 period. The Commission has, however, agreed to a stretch-out arrangement during the period from the end of March 1962 to December 31, 1966.

• **Hungary-Russia** A plan of cooperation for 1960 has been signed in Moscow by representatives of the Hungarian and Soviet Academies of Sciences. Under its terms, fifty scientists from each country will interchange visits and scientific information will be exchanged.

• **Russia-USA** Following earlier discussions (see *Worldview*, November) a memorandum providing for a programme of reciprocal exchanges in the field of the peaceful uses of nuclear energy has now been signed by the two countries

for the year 1960–61. This agreement covers exchange of information and visits of personnel, the possibility of undertaking joint enterprises and the making available of new instruments on a reciprocal basis.

• **Argentina** A series of preliminary geological investigations carried out in the province of Santiago del Estero has revealed the existence of radioactive mineral deposits. Further studies are now being made.

• **Canada** The £M32 power project, NPD, has reached the halfway mark in its construction. It is scheduled to start delivering power by mid-1961.

• **Canada** Senior officials of the United Kingdom AEA visited Chalk River recently to attend the Seventh UK-Canada Technical Policy Conference. The AEA's work on the preliminary design of a steam-cooled heavy water reactor was reviewed during the discussions.

• **Finland** Included in the Finnish request to the IAEA for supplies of enriched uranium was assistance in fabricating the fuel into elements. The Agency has transmitted this enquiry to three member states, the UK, USA and USSR.

• **France** Following tests on the main reactor vessel of the 60 MW EDF-1 at Chinon it is anticipated that the startup will be delayed as it has been found necessary to cut out and reweld a number of joints in the plates.

• **Germany** The Federal Government has promised to guarantee up to approximately DM100M, nearly £M58, for the Arbeitsgemeinschaft Kernkraftwerke Stuttgart (AKS) project to build a 150 MW OMR under the joint Euratom-USA power programme.

• **India** When President Eisenhower formally opened the US exhibit at the World Agriculture Fair, New Delhi, he started up a Triga 100 kW reactor.

• **Indonesia** The Minister of Reconstruction and Development, Chaerul Saleh, has been appointed deputy chairman of the Indonesian Atomic Energy Council, thus all the council members are either ministers or deputy ministers.

• **Japan** The contract for the 150 MW gas-cooled reactor which the UK General Electric Co. is to build at Tokai Mura was signed in Tokyo on December 22.

• **South Africa** Dr. A. J. A. Rouse, director of the Union's Atomic Energy Board's £M4 development programme has stated that a comparatively small research reactor will be brought from overseas and later the Union will develop and build a high flux reactor of its own.

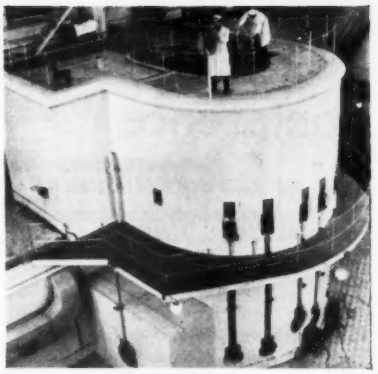
• **Switzerland** The proton synchrotron built by the European Organization for Nuclear Research, CERN, at Meyrin, near Geneva, has recently been operated at its full power of 24 MeV.

• **United Kingdom** A technical symposium, attended by 90 scientists and engineers, was recently held at Bournemouth. It reviewed the use of graphite in reactor fuel elements with special reference to the OEEC Dragon project.

• **United Kingdom** Mr. A. Robens, MP for Blyth, has been appointed consultant of labour relations by Atomic Power Constructions Ltd. for their Trawsfynydd project.

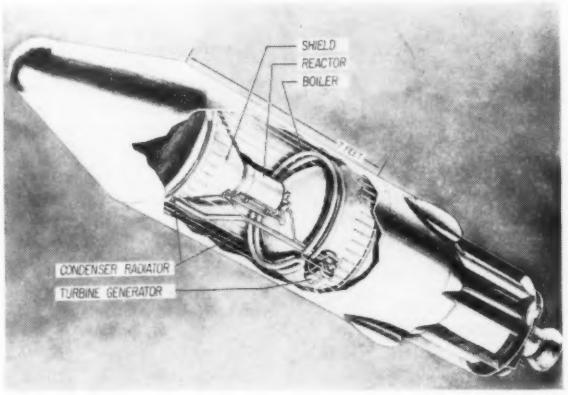
• **United States** Two critical assemblies, the Zero Power Reactor 6, ZPR-VI, and Zero Power Reactor 9, ZPR-IX, together with a low-flux special purpose research reactor, Juggernaut, are to be built at the Argonne National Laboratory.

• **United States** The AEC, in conjunction with the Department of Defense is to place an increased emphasis on the development of advanced fuel elements for the direct cycle phase of its Aircraft Nuclear Propulsion programme.



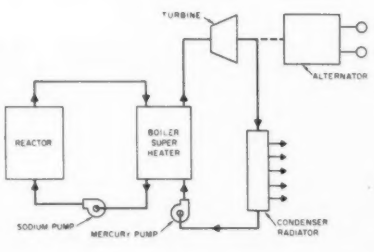
NEW USSR FACILITY The Institute of Physics of the Georgian SSR Academy of Sciences at Tbilisi has now brought this 2 MW reactor into service

• **International** The first volume of the proceedings of the Stresa Conference has been issued by the OEEC. It includes two special ENEA studies on 'Estimates of Nuclear Energy Production in Europe 1958–1965', anticipated to cost some £M1071, and 'Financing Nuclear Energy Programmes and Relations between State and Industry'.

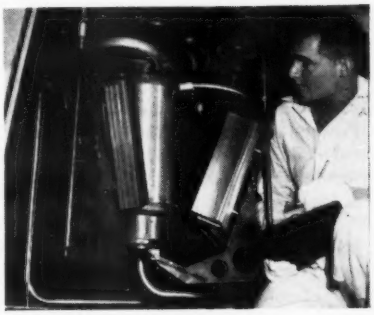


SNAP II
Reactor power plant designed to operate continuously and unattended in space for a year

The 50 MWt nuclear auxiliary power system, SNAP II, has potential advantages of low weight, high power and long life over the chemical batteries and solar cells used in recent space satellites



The reactor was designed and constructed for the United States AEC by Atomics International. Fuelled with enriched uranium it is now undergoing ground tests at the Commission's facility in the Santa Susana mountains



Waste disposal conference

Our special correspondent reports from Monaco

OVER 300 experts attended the first international scientific conference on the practical aspects of the disposal of radioactive waste, held at the Oceanographic Museum here for five days in November. The meeting was sponsored by the International Atomic Energy Agency, IAEA, and the United Nations' Educational, Scientific and Cultural Organization, UNESCO, and supported by the Food and Agricultural Organization, FAO. Representatives of the World Health Organization, WHO, and World Meteorological Organization WMO, attended and altogether 32 countries and 11 international organizations were represented.

AT MONTE CARLO H.S.H. Prince Rainier of Monaco welcomes delegates to the conference. On the left is Mr. Sterling Cole, Director General of IAEA and on the right is Mr. V. Veronese, Director General, UNESCO

The discussions covered the problems associated with the origin and nature of possible wastes from nuclear ships, fuel processing, isotope applications and nuclear accidents; disposal procedures in air, soil and water; economic factors; and the need for cooperative research.

The object of these talks was to implement the various international directives, such as the IAEA's Statute to establish or adopt 'standards of safety for protection of health and minimization of danger to life and property . . .'

During the meeting it become obvious that the UK Atomic Energy Authority's policy of sea disposal was strongly frowned upon. Russian delegates said quite bluntly that radioactive waste should not be dumped but sealed up and safely stored indefinitely.

French Atomic Energy Commission personnel from Saclay reviewed methods now being tested which included the sealing of solid wastes in large concrete blocks and sludge in drums buried in concrete tombs. So far, France has not dumped any radioactive waste into the sea. Atomic Energy of Canada Ltd. are also using various storage methods and at the Hanford Atomic Products Operation at Richland, Washington, chemical treatment is being employed to reduce the volume of stored materials. In some cases a reduction of up to 90% has been achieved.

Volumes to be handled

Mr. Sterling Cole, Director General of IAEA, said that the problem was one of storage rather than disposal and that with only the present limited power programme it has been estimated that some 10½ million gallons of high-level waste solutions from spent reactor fuel were produced annually. Mr. F. R. Bruce, of the Oak Ridge National Laboratory, amplified these figures by saying that in the US alone it was estimated that the nuclear power industry would have produced waste amounting to about three million curies by 2000. Each ton of uranium fuel reprocessed produces 1200 gallons of radioactive waste.

The main danger, according to Mr. H. D. Schulte, group leader of the industrial hygiene group at Los Alamos, lies in the operation of fuel reprocessing plants; the normal operation of a reactor raised no great problems.

AEA's Mr. R. H. Burns said that special treatment was carried out at AERE, Harwell, before low-level liquid waste was discharged in the Thames and no solid waste was buried at Harwell so that any danger of seepage into the river was avoided. Similar precautions are being taken in Denmark, reported Mr. Ib. Larsen. A decontamination plant has been built at Risø which is capable of reducing activity in liquid waste to less than one tenth of the maximum standard set for drinking water.

Russian ideas

The fixation of radioactive material in glass under high temperature was at present being studied in the Soviet Union, Mr. P. V. Zimakov stated. This method increases safety in that it renders the waste material solid and reduces its solubility before it is buried. Work is going on to improve the technique as complete insolubility has not yet been achieved.

Considering the use of deep waters as dumping areas, Mr. L. A. Zenkovich of the USSR said that in the Soviet Union they had come to the conclusion that no isolation of deep waters existed in the world's oceans. A turbulent mixing of various layers took place down to depths of 36,000 feet. This opinion was not shared by the United States and according to Mr. M. B. Schaeffer, the rate of mixing in the Pacific Ocean seemed to indicate that a water particle remained well below the surface for a period of between 1000 and 2000 years.

Concluding the panel discussion on sea disposal, Mr. Roger Revelle of the Scripps Institute of Oceanography, California, said that it was evident that ten times more money and facilities were needed for research.

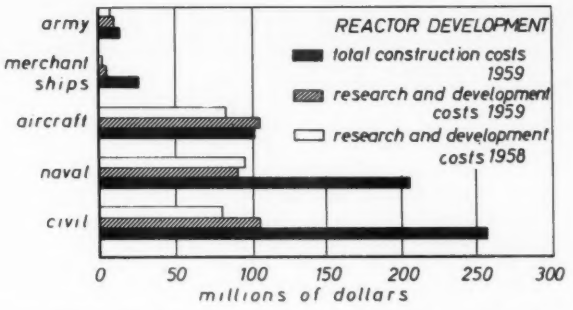
Possible solutions

Dr. H. Jammot, of France, who attended the conference as a representative of the International Commission for Radiological Protection, ICRP, said that the meeting had shown that within the permissible radiation limits set by ICRP, several solutions to the problem of waste disposal were available.

Summing up the work of the conference, Mr. G. W. C. Tait, Director of the Division of Health, Safety and Waste Disposal of the IAEA, said 'one must take into account physical, chemical, geological, oceanographic and biological conditions as well as the habits of the organisms in the area.'

AEC financial report for 1959

Activities and costs greatly increased



THERE CERTAINLY does not appear to be any recession in the American nuclear engineering industry from the US Atomic Energy Commission's financial report for the year ending June 1959, which shows that some $M7292, nearly £M2900, had been spent on plant and equipment.

The AEC's intensified efforts in nearly all fields of nuclear energy brought the net cost of operations to $2·5 billion for the year which represents an increase of nine per cent over 1958. With the exception of the naval class of reactors, which by now have been fairly well established, the reactor research and development effort has been increased by 16%.

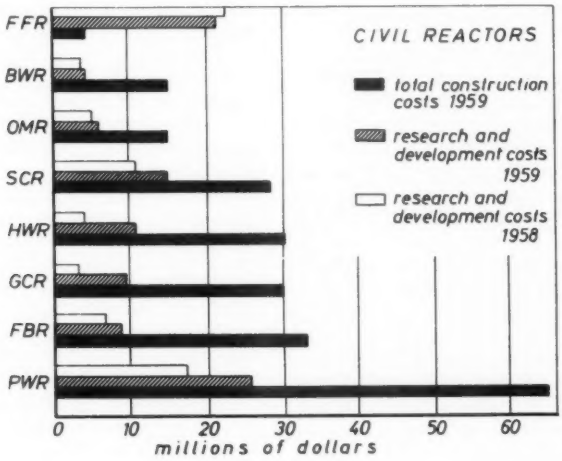
Industrial power

During the financial year 1959, the AEC's research and development costs for civilian power reactors were $M105 for specific reactor concepts and in addition they participated in a number of cooperative projects which included 110 MWe Yankee Atomic Electric Co due to startup July 1960; 94 MWe Power Reactor Development Co due to startup August 1960; 20 MWe Rural Cooperative Power Association due to startup January 1961; 10·5 MWe City of Piqua due to startup September 1961; 75 MWe Hallam District Consumers Public Power due to startup November 1961; 62 MWe Northern States Power Company due to startup May 1962; 17 MWe Carolinas-Virginia Nuclear Power Association due to startup June 1962; 50 MWe East Central Nuclear Group due to startup December 1963; 40 MWe Philadelphia Electric Company due to startup December 1963 and fast breeder reactor technology. The financial breakdown behind this 478·5 MWe cooperative power programme is:

	Cumulative Costs to June 30, 1959		Total Estimated Costs	
	AEC	*Participants*	*AEC*	*Participants*
	(in millions of dollars)			
Research and development	20·7	16·6	93·3	49·6
Nuclear plant construction	4·1	26·2	40·7	138·7
Conventional plant construction	—	21·8	—	98·8
Waiver of fuel use—charges	·1	—	13·7	—
Total	24·9	64·6	147·7	287·1

Marine propulsion

Over the past year, the AEC costs for research, development and tests of specific reactors for the application of nuclear power in the maritime service have been more than trebled. Construction costs for the NS *Savannah* are estimated at $M45 of which $M26 will be provided by the Commission for the reactor and related facilities and the balance of $M19 for the hull and outfitting will be provided by the US Maritime Administration. Preliminary design work has been carried out on marine-type BWRs and GCRs and for the latter the Maritime Administration has spent nearly $M2 on the associated turbines and other machinery. This joint programme is to be continued through the current year.



Physical research

Costs relating to chemical, metallurgical, physical and controlled thermonuclear research have increased by some 28%, to $M112. In addition, research in the life sciences has cost more.

Cheaper fuel

While the uranium concentrate purchases by the AEC totalled $M689, an increase of 23%, the cost of production of nuclear materials decreased by $M37 even though the quantities produced were increased. From the beginning of the AEC's programme to July 1, 1955, 83% of the uranium purchased came from foreign sources. Between July 1, 1955 and June 30, 1962 it is proposed that 47% will came from domestic sources and 53% from overseas. Of the outstanding contracts for the period June 30, 1962 to December 31, 1966, 84% of the uranium which the AEC is committed to buy will come from US plants. During the 1959 financial year, the sales of source and special nuclear material were trebled and totalled some $M70.

Educational assistance

An extensive programme of assistance to colleges and other educational institutions has been maintained and a number of schools and courses have been sponsored by the AEC for qualified scientific students in the fields of reactor and radioisotope technology. In addition, reactors, subcritical assemblies and similar items have been obtained by 128 universities and colleges with the aid of AEC funds.

Future costs

From the figures included in the 1959 Annual Financial Report it is evident that the AEC will continue to have to foot an ever-increasing bill. Against this, however, it can be seen that the Commission's programme will lead the American nuclear engineering industry into a well-established and important position in the US economy.

The heads of the International Atomic Energy Agency, Euratom, and the European Nuclear Energy Agency report their progress in 1959

The year in the International Agencies

THE WORK OF THE INTERNATIONAL ATOMIC ENERGY AGENCY

W. Sterling Cole,

Director General

AT THIS TIME last year I wrote for NUCLEAR POWER a summary assessment of the work and functions of the International Atomic Energy Agency. In making a similar assessment this year I am forcefully struck by the changes that have occurred in this brief period of twelve months. Last year I mainly referred to plans and projects; now I can speak of activities and achievements.

Coming to grips with reality

Last year we heard many expressions of dissatisfaction or impatience with what was called 'the Agency's slow start'. Although I did not find the criticisms justified, I certainly shared some of the impatience. This year it seemed to be generally acknowledged that the Agency, in the words of the General Conference President, Mr. Furuuchi of Japan, 'had found its feet' and 'had come to grips with reality'.

The International Agency has work well under way in the field of safety. In December 1958 we issued a manual on the safe handling of radioisotopes. More detailed advice on the use of radioisotopes will be given in two substantial addenda, one dealing with health physics and the other with medical aspects of the problem. The manual will be revised from time to time as operational experience of its use is reported to the Agency. Similar manuals will be drawn up for the operation of critical assemblies and research reactors. Power reactor safety also presents problems, particularly in regard to siting.

The Agency also arranges for health and safety advice and evaluation of specific projects. On the request of the Swiss authorities, a panel of experts recommended and serviced by the Agency evaluated the safety aspects of a Swiss reactor project and issued a 'certificate of fitness'. We have had further enquiries for services of this kind and such international certification might well develop into an important function of the Agency.

An unfortunate accident took place in the course of an experiment with a critical assembly at Vinca, Yugoslavia, in October 1958, and the Agency, together with the Yugoslav authorities, is now investigating the causes and precise happenings. This investigation will yield valuable information which could have significant bearing on similar installations in other countries and the effectiveness of medical treatment of heavy radiation exposure.

An Agency panel of experts from nine countries, under the chairmanship of Mr. Harry Brynielsson, head of the Swedish Atomic Energy Company, has been at work since October last year on problems relating to disposal into the sea. Sea disposal of radioactive wastes is of course of special international interest; waves and currents do not respect national frontiers or three-mile limits.

It is quite possible, for instance, that the International Agency will maintain a register of all radioactive waste disposals into the sea and call upon Governments to give us the necessary information. With the register might be coupled a system of advance notice of intent, annual reports on the state of such sites and perhaps a monitoring programme.

In this connexion I wish to draw attention to a proposal laid before the Agency at the General Conference a few weeks ago by the United States delegation. The Agency should, according to this proposal, initiate a programme to determine the feasibility of establishing regional or international burial grounds for packaged or solid wastes and investigate the designation of specific sea disposal sites and establish an international registry for sea disposal operations. It should also determine the safe capacity of international rivers to dilute radioactive wastes. These suggestions seem eminently practical and we hope to be able to act upon them without delay.

The Agency's largest scientific conference so far was held recently at the oceanographic museum in Mon-

aco. It covered practical aspects of the whole range of radioactive waste disposal measures and techniques.

The technique applied by the Agency in attempting to arrive at international minimum standards in the health and safety field seem to work satisfactorily. After a particular problem or a difficult area has been identified and the groundwork finished by the specialists of the Agency's staff, a proposal for the calling together of a panel is considered. We select experts from different countries to serve on such advisory panels. These experts are appointed in their individual capacities, but they are often selected in consultation with the Member Governments concerned and we always try to obtain as wide a geographical distribution as possible. The panel is thus most likely to reflect the differences of experience, practice and policy that might exist and when they reach general consent, which they seem able to do in most cases, the ground is well prepared for acceptance of the recommendations on the governmental levels.

Law, security and assistance

A group of international legal experts from the main countries concerned is now completing its draft of a convention dealing with civil liability.

The Secretariat, a truly international one, has drafted sets of principles and regulations to guide the Agency's safeguards activities. These have been submitted to the Board of Governors and I reveal no confidential information in saying that no other single subject has taken more of the Board's attention and time. The Board has now provisionally agreed to the guiding principles and will consider the detailed regulations, based on the provisional regulations, early in 1960.

Many aspects of the safeguards system necessitate further research and to that end we have placed a series of research contracts with institutions in Member States. The Agency is also preparing a manual on the principles and specific applications of the accounting for source and special fissionable materials. The proposed procedures are checked on reactors and uranium processing plants in some Member States, to make sure that the proposals are practicable and provide adequate control.

Our assistance activities cover the entire field of peaceful uses of atomic energy: fellowships, training, exchange of professors, experts, equipment, advisory missions, scientific and technical information, research. These are what I would call our routine activities and they have increased considerably in the past year. Here I shall only discuss briefly two associated aspects of this assistance: the supply of materials and assistance in the production of nuclear power.

Disappointment has been voiced over the fact that IAEA has not in any measurable degree been called upon by Governments to serve as a world clearing house for fissile materials and that no power stations have been built as a result of Agency action.

This disappointment, although easy to understand and sympathize with, stems really from the exaggerated hopes embedded in some early estimates of the competitiveness of nuclear power and in particular of nuclear power in technologically less advanced regions. It is not the sources of supply that the Agency is lacking; on the contrary, numerous and generous offers have been received. There is not, however, an active demand. In addition, such demand as there is can be amply met, contrary to earlier beliefs, by normal international trade and bilateral or multilateral arrangements. The terms so far available from the Agency are, in financial terms, no more advantageous than those obtainable elsewhere.

The fact that the Agency in spite of this situation has completed one uranium transaction and has received some enquiries for the supply of enriched uranium, proves that some countries at least have recognized the advisability of obtaining their nuclear materials from an international public agency in which they have a seat and vote rather than through other channels.

There are probably given situations in which nuclear power even now would be fully competitive with conventional sources and it is likely that the Agency will in the very near future be associated with the thorough pre-investment studies necessary before a country embarks upon a nuclear power project. The Agency's function as a supplier of nuclear fuels and its role in assisting countries to acquire nuclear power are therefore far from abandoned; they are only delayed because of the realities of the current situation.

THE WORK OF THE EURATOM COMMISSION

Etienne Hirsch,

President

AS EURATOM (the European Atomic Energy Community) enters its third year, it is possible to take stock of some of its achievements. The Community is still young, and still has a long way to go; but to some extent it has already begun to have a history of its own and to make its impact felt in the atomic world.

The broad reasons for the creation of Euratom are still valid today. But at the time when the Euratom Treaty was drafted, they were spurred by a further sense of urgency, due to the worsening situation of Europe's energy supplies. The Suez crisis, in the summer and autumn of 1956, made this situation dramatic. Today, it no longer seems so. Europe's energy consumption in 1958 was in fact two per cent less than in 1957. In 1959, its energy consumption, estimated at the equivalent of some 415 million tons of coal, will probably be slightly lower than the 1956 figure. At the same time atomic energy faces the growing importance of oil and new resources of natural gas, as well as the construction of new tankers and the continued rise of productivity in American coal mines. All this means that atomic energy must meet fiercer competition. Two years ago, it was forecast that the price of a ton of coal c.i.f. on the European coast would be around $18; today, American steam coal can be bought in Rotterdam at about $14 a ton, and the price of imported oil is even lower. Most modern thermal plants are now able to produce electricity for 1·5 mills less than was expected two years ago. For a 150 MW reactor with a load factor of 75%, producing one thousand million kilowatt-hours per year, this represents an added handicap of 1·5 million dollars per year. Furthermore, the installation cost for nuclear power plants has risen

slightly higher than was originally estimated.

All these changes have diminished the sense of urgency prevailing at the time of the Suez crisis. But while these changes may require some flexibility in the time-table, it now seems likely that a large part of the US-Euratom joint power programme will be achieved. In response to the invitation for proposals issued in April 13, 1959, five utility groups submitted letters on May 29, expressing their intention to participate in the first phase of the programme. Each of these utilities, by October 20, had confirmed this intention.

As far as long-term prospects are concerned, the need for atomic energy remains as great as ever. The consumption of electricity in Western Europe keeps doubling every ten years. In 1958, our six member countries produced 230 thousand million kilowatt-hours. For a population nearly equal to that of the United States, this amounts to less than ¼ of the production of the United States.

While the European University is still for the future, Euratom's nuclear research programme is already under way. During the first five years, $215 million will be spent upon it, part in the form of research contracts with other bodies, and part in the Euratom research centre itself. Contracts already made include one with the French Atomic Energy Commissariat, for joint work on fusion, one with Kema in the Netherlands, and one with the Belgian Centre for Nuclear Studies. A second fusion contract is being negotiated with the Max Planck Institute in Munich, and a further contract, for work on radiobiology, is planned with the TNO in the Netherlands.

Three centres planned

The establishment of the Euratom research centre, moreover, is making good progress. Since an important aspect of Euratom's role in the research field is to supplement and coordinate the work of its Member States, it has decided not to add further new centres to the many that already exist in the Community, but to utilize as far as possible the facilities already set up, in a sense subtracting from rather than adding to their number. On July 22, 1959, Euratom signed with Italy an agreement whereby an important part of the joint Centre will be settled in the existing research establishment at Ispra: other parts are likely to be at Petten in the Netherlands and Karlsruhe in Germany. Euratom's expenditure on Ispra will amount to some $24 million for facilities and equipment and some $15 million operating expenses up to the end of 1962. By that time, Ispra will house some 1500 research workers and assistants.

In addition, Euratom is undertaking a 100-million-dollar joint research and development programme as part of its Agreement for Cooperation with the United States. Already, some 400 proposals have been received, of which nearly 100 are joint American-European proposals. This success shows that industry on both sides of the Atlantic has faith in atomic energy. Moreover, the unique features of the programme—direct association between American and European firms, joint financing, joint selection of proposals, and equal sharing of results—provide a working model of the kind of efficient and intimate relationship which Euratom would like to develop with all its nuclear partners.

But the US-Euratom Joint Programme, important as it is, represents only one aspect of Euratom's activities. In other fields too it has made a good start. Its basic standards for health protection against ionizing radiation were worked out and published a little less than a year ago. It is now seeking to bring about a harmonization of national legislation on this subject, as well as to follow through in other fields the implications of the basic standards. Meanwhile, Euratom has set up its own control and security systems, to ensure that fissile material is not diverted from its stated use.

In the more directly commercial field, it has established a common market for nuclear materials and for the elements necessary to build nuclear plant. It is busy perfecting the system whereby technical data may be made more freely available throughout the Community, while at the same time safeguarding normal patent rights. It is also active in the field of insurance against nuclear risk, where it collaborates closely with countries of OEEC. In the framework provided by OEEC's European Nuclear Energy Agency, Euratom is working with its European partners on three important joint projects. The first is the Halden reactor in Norway; the second is the Dragon high-temperature reactor at Winfrith Heath, England, for which Great Britain and Euratom are sharing 80% of the cost; and the third is the Eurochemic Company, for which more than 50% of the capital is coming from the Euratom countries.

Moreover, in addition to the US Agreement, Euratom has already contracted two further international agreements, one for cooperation with the United Kingdom, on February 4, 1959, and the other on October 6, 1959, with Canada, for a joint research and development programme centered on heavy-water reactors. Finally, moreover, Euratom maintains close relations not only with such bodies as the International Atomic Energy Agency in Vienna and the European Nuclear Research Centre at Geneva, but also with the many private and semi-public organisations that are active in this field.

THE WORK OF THE EUROPEAN NUCLEAR ENERGY AGENCY

Pierre Huet,
Director

SINCE THE CREATION of the European Nuclear Energy Agency two years ago a temporary slowing down of industrial expansion, coupled with both increased availability and more efficient use of conventional fuels (notably oil), has led to an easing of the pressure for the urgent large-scale production of nuclear power.

Despite these changes, the international work of OEEC in the nuclear field has lost none of its importance for the long-term solution of energy problems. Already there are signs of renewed economic expansion, industrial activity is again increasing, and it is clear that in a few years' time (between 10 and 20 at the most) the countries of Europe will be compelled to turn to nuclear power for the maintenance of their industrial economy and domestic living standards.

The three current international projects of the European Nuclear Energy Agency—Dragon, Eurochemic, and the Halden Reactor Project—represent in total an expenditure of some £23 million during the next four to five years. This is relatively small compared with the cost of the national nuclear programmes of the OEEC Member countries, which total approximately £350 million a year, or even with the first 5-year budget of Euratom which exceeds £70 million.

Work on the Dragon High Temperature Reactor Project, originally suggested by the British in March 1958, began last April. Main object is to build an experimental 10 MW reactor at the Atomic Energy Establishment, Winfrith, and to investigate the possibilities of such reactors for power production and, perhaps, for propulsion purposes.

Preparatory design work for the Company's £4 million irradiated fuel processing plant, which had been in the hands of an ENEA Study Group at Mol, Belgium (where the plant is being built) came to an end last July when the Company itself was formally constituted. This followed ratification of the 1957 Convention by the necessary number of signatory countries, representing 80% of the scheduled share capital.

Since then the administrative machinery of the Company has been taking shape, the 240-acre site at Mol has been purchased, and negotiations for the construction of the plant and laboratories have begun. The plant, which initially will be capable of processing 100 tons of fuel per year, is expected to be completed in 1963.

Early in 1959 Spain, who had for some time been associated with much of the work of the Organization and has since become a full member, joined the project. Spain's participation has led to an increase in the capital of the Company from $20 million (approximately £7·2 million) to $21·5 million (approximately £7·7 million).

An important recent development in the structure of the Company has been the transfer of part of the Belgian, French, German, and Dutch holdings to private industry in these countries. Eurochemic has thus become a truly mixed-investment company with both public and private capital.

Health and Safety

The programme to develop, for all Member countries, basic health and safety criteria for the protection of the population against nuclear hazards led, on June 12, to the adoption by the OEEC Council of a Decision requiring Member countries to ensure adequate health protection for all persons who might be exposed, whether occupationally or otherwise, to ionizing radiations. Appropriate safeguard measures to meet emergencies or accidents involving these radiations were also stipulated. Finally, all countries were called upon to report to ENEA on their legal and administrative measures in this field.

The Council Decision further recommended that the health protection measures called for should be based on common norms developed by an international group set up by the Agency in May 1958, and comprising leading radiation experts from the OEEC countries and Euratom. These norms were themselves based on the recently revised recommendations of the International Commission on Radiological Protection (ICRP).

A necessary step in controlling the radiation dose received by the population is the regular measurement of ambient radioactivity and contamination in air and water. Monitoring stations have been or are being set up in most OEEC countries for this purpose, and ENEA has initiated an exchange plan for the communication and correlation of data obtained from these stations.

Third Party Liability and Insurance

ENEA has drafted a European Convention on third party liability in the event of nuclear accidents, and this is now in the final stages of negotiation between European governments.

The basic principles of the Convention are (1) that the operator of a nuclear installation shall be absolutely and exclusively liable for damage arising out of nuclear incidents connected with the installation, (2) that the liability shall be limited in amount to $15 million (which at present appears to be the maximum amount for which insurance cover could be obtained) for any one incident, (3) that the time during which claims can be made shall be limited to ten years from the date of the incident, (4) that the operator shall be bound to provide financial security, by insurance or otherwise, for his liability, and (5) that a single competent court, that of the place where the incident occurs, shall decide all actions arising from the incident and shall have its judgments automatically enforceable in all OEEC countries. Special rules will apply in cases of incidents during the transport of radioactive fuels and other materials.

The Convention leaves it open to each signatory state, if it wishes, to provide for supplementary compensation if damage should exceed the limits laid down.

Security Control

At the same time as signing the Eurochemic Convention, two years ago, all OEEC Member countries signed a Convention on the establishment of a Security Control designed principally to prevent the use of joint nuclear facilities for military purposes. Following ratification by the necessary number of signatories this Convention entered into force last July.

The control system is based on the requirement that any undertaking to which it applies must keep account of all fissile material used, and must permit its accounts to be verified by international inspectors. Operation of the system will be centred in an international Control Bureau set up within ENEA. Sanctions may be prescribed in cases of non-observation of the Convention, subject to the right of the government or undertaking concerned to appeal to an international tribunal.

Information

A very important aspect of the work of ENEA is the interchange of information. This can be promoted in many ways, including conferences, symposia and seminars, international training courses, and international working groups and committees.

ENEA has established many such groups from time to time, including a top-level Committee on Co-operation in the Reactor Field, and the three joint projects, the health and safety recommendations, and the third party liability Convention (to give a few examples) are the results of this method of working. The recently formed European-American Nuclear Data Committee, comprising experts from the United States, Canada, the UK and other OEEC countries, will enable collaboration on a much wider scale than hitherto on the vast work of determining nuclear properties of materials, in particular nuclear cross-section measurements.

Recent examples of ENEA-sponsored information conferences and symposia were the Stresa (Italy) Conference on Industrial Prospects in Nuclear Energy and the Riso (Denmark) Symposium on Technical Methods in Health Physics, both of which took place last May.

Less spectacular but nonetheless important are the regular information seminars organized by ENEA at national nuclear research centres in Member countries. In 1959, seminars for some 50 university professors from nearly all the OEEC countries were arranged during July at both Harwell and Saclay.

Following the initial country by country survey of the world's nuclear power programmes which they made last January, a specially-commissioned team of economists and technical experts reviews progress made since then

National programmes in 1959

EUROPE

AUSTRIA

A RESEARCH centre is now being set up at Seibersdorf, near Vienna. A 5 MW pool-type reactor, supplied by AMF Atomics, will be in operation in 1960 and a 30 kW Triga reactor is on order. It is proposed that a 100–150 MW nuclear power station should be in operation by 1965/67; the choice at present would appear to lie between a UK Calder-type station or a US BWR.

BELGIUM

NO OFFICIAL nuclear power programme has been announced but it was envisaged until recently that four power reactors might be in commission by about 1967 with a total output of some 550 MW. The first would be the 150 MW station under consideration for the US/Euratom programme, to be jointly owned by the Belgian Centre et Sud Group and the Electricité de France and sited at Givet in the Ardennes (France). This would be followed by the further stations, including possibly a fast reactor. On the other hand, the proposal for a 150 MW station at Mol to be jointly owned by the Interescaut Co. and the Limburg Electricity Co. of the Netherlands has now been abandoned. Total nuclear capacity in 1975 has been estimated at 1800 MW.

At Mol the 50 MW materials testing reactor and the 11·5 MWe pressurized water reactor, supplied by Westinghouse, are both now scheduled for operation in 1960.

BULGARIA

WORK has started at Sofia on a 2 MWt research reactor, provided by the Soviet Union, and similar to the one now working in Hungary ; it should be completed in 1960.

CZECHOSLOVAKIA

THE FIRST nuclear power station in Czechoslovakia is planned to go critical in 1963 at Bohunice, near Bratislava. It will use natural uranium, be gas-cooled and will be heavy water-moderated, but whether it will have a pressure vessel or a pressure tube assembly has not yet been decided. Various reports give its capacity as 100 or 150 MWe.

This power station is being built with considerable help from the USSR ; many of the nuclear components will be imported, but indigenous uranium will come from the Joachimstal mines ; there is no record of a Czech heavy water plant, and it is unlikely that heavy water could be cheaply manufactured in Czechoslovakia ; it will have to continue to be imported. In these circumstances it is difficult to see how the Czech nuclear power programme can ever be truly autonomous until, perhaps, the very advanced stage of fast breeder reactors.

Nevertheless, the Czech power programme remains an ambitious one, though it is now doubtful whether they will achieve their aim of having one third of their electricity supplied from nuclear energy by 1970.

DENMARK

NO important developments have taken place in 1959, though steady research continues at Risø.

FINLAND

A TRIGA Mark II reactor is to be installed at a site being prepared near Helsinki and is expected to be in operation before the end of 1960. A projected critical assembly is scheduled to come into service during the first half of 1961 and will use 10% enriched fuel. The Finnish Government has requested the International Atomic Energy Agency to supply the fuel for both these installations.

FRANCE

THE French nuclear power programme, although modest in size, provides the nearest immediate comparison with efforts in the UK. It is, therefore, all the more to be regretted that information about it is difficult to come by and frequently contradictory. This point was made by a Senator in a recent debate in Paris; the Minister for Atomic Energy, M. Soustelle, accepted the criticism, and promised that something should be done.

The part the nuclear power programme is expected to play in the economy in the immediate future has changed somewhat. M. Soustelle has said that electricity from the Electricité de France stations now being built (EDF–1 and EDF–2) will not be competitive with electricity from conventional sources. As a consequence, more emphasis will be placed on perfecting techniques now being developed, and on handing on this knowledge to French industry.

This situation is in part due to new sources of cheap energy now becoming available to France, in particular natural gas from Lacq and oil from the Sahara (though this latter, because of its high petroleum content, poses some intricate economic problems). Natural gas from the Sahara, via a pipeline through Spain, would provide an even cheaper supply of primary energy.

In 1959, for the first time, some information was given on economics. It transpires that the cost of EDF–1 will be

about £M12, and of EDF–2 about £M22. This is equivalent to a cost of £170 per kW for the 70 MWe station, and £130 per kW for the 170 MWe station. This latter price is in line with the first round of UK stations, though EDF–2 will be coming on line somewhat later than its UK opposite numbers.

The more interesting information concerns EDF–3 and EDF–4. The credits for these stations have been announced; they amount to £M38 and £M50 respectively. Thus, even assuming that there are no further economies of scale, and that the price per kW of the later stations is the same as of the earlier, on this reckoning EDF–3 will have a capacity of 300 MWe and EDF–4 of 400 MWe. No economies of scale would apply if the later stations were virtually two reactor replicas of EDF–2, but this is on the whole unlikely. More probably, improvements will be made, and these estimates of capacity might prove to be on the conservative side.

The nuclear power programme remains officially unchanged at 850 MWe by the end of 1965. Unlike most other countries, however, it is difficult to see how France can avoid building more than the programme allows for.

The EDF stations, it has always been stated, will be built at approximately eighteen-month intervals. The gap between EDF–1 and EDF–2 has been narrowed by difficulty experienced in welding a 4 in. thick steel pressure vessel: EDF–1 will not probably now go critical until early 1961, a year later than planned.

On these calculations, the French Power Programme would be as follows:

STATION	CAPACITY MWe	CRITICAL
EDF–1	70	Jan. 1961
EDF–2	170	Jan. 1962
EDF–3	300	July 1963
EDF–4	400	Jan. 1965

Total 940 by 1965

A total of 940 MWe should, therefore, be installed, the last in Jan. 1965. Allowing for six months' commissioning and a six months' delay in construction, there would still seem a good chance that nuclear capacity in France, including plutonium production reactors and reactor experiments, will amount to 1000 MWe by the end of 1965.

On longer term plans, M. Perrin, the High Commissioner for Atomic Energy, has spoken very recently of two 500 MWe stations to be sited at Marcoule and run in conjunction with the French diffusion plant.

The diversification and decentralization of the research and development side of the Commissariat à l'Energie Atomique's (CEA) activities which was promised, is now becoming apparent. The research centre at Grenoble was opened early in 1959, with its 1·2 MW swimming pool reactor Melusine.

The CEA have decided to place a number of their activities in Provence, doubtless because of the attraction of cheap power—not to mention the splendid surroundings. The plutonium production centre is already there, at Marcoule, on the Rhône opposite Orange. In addition, the French diffusion plant is to be built, slightly to the north, at Pierrelatte, on an island formed by the Rhône and the feed channel to the largest hydro-electric power station in France, the Usine André Blondel. Finally, the French Winfrith, Idaho or Ulyanovsk is to go to Cadarache, on the Durance, not far from Aix-en-Provence.

Plutonium Production (Marcoule)

Last April G–2 started supplying the grid with 9 MWe, the first nuclear electricity in Western continental Europe; G–3 also went critical in July. These two reactors are now being worked up to their full joint electrical output of 80 MWe gross or 50 MWe net. Plutonium production from the chemical separation plant is continuing, and should ultimately amount to 100 kg per annum from the three Marcoule reactors. There was a fire during the year in the air-conditioning system in this plant, but apparently no external damage was caused.

Diffusion Plant (Pierrelatte)

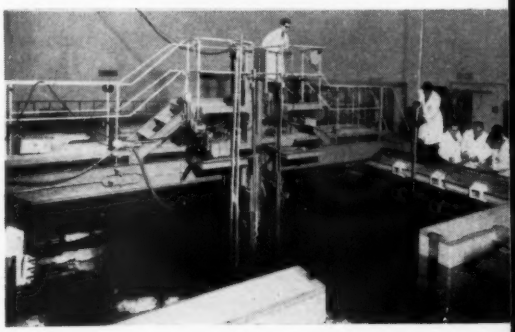
A little more is now known of the projected diffusion plant at Pierrelatte. It will initially produce 3% U–235 uranium only. The feed will be 350 metric tons a year; this would give about 30 metric tons of 3% uranium, the precise quantity depending on the cost of electricity.

One of the purposes of the plant mentioned in last year's review was the provision of slightly enriched fuel for naval propulsion. Since there is now an agreement between France and the US for the supply of highly enriched material for naval use, it seems likely that the material from the Pierrelatte plant may become available for civil research and power.

Two of the advanced reactor systems considered to be of special interest will be built on the new site at Cadarache. Brenda, a gas-cooled, beryllia-moderated, enriched uranium reactor will have a thermal output of 10–17 MW. The sodium-cooled Fast Reactor, Rapsodie, will also be going there ; it is planned to have an output of 10MWt. No information is yet available as to its fuel, but the absence of any arrangement on this subject with the US, combined with

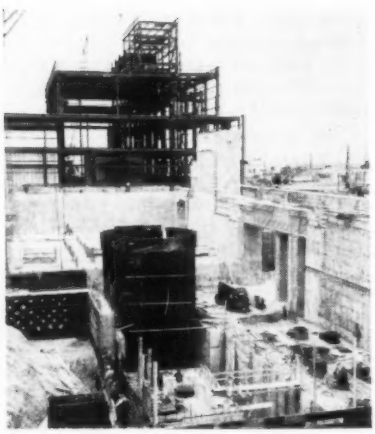
ITALY The first British designed power station is at present under construction at Latina where the UK Nuclear Power Plant Company is erecting a 200 MW station

AUSTRIA Mr. Sterling Cole, Director General of IAEA and Dr. Henry Seligman on the site at Seibersdorf near Vienna where the agency's laboratory is being built



ITALY At Saluggia SORIN are now operating the first privately owned reactor, a 1 MW swimming pool type, on industrial research for a group of Italian companies

UNITED STATES This boiling water reactor power station, the world's first, was completed recently at Dresden. Beyond the entrance is the sphere containing the 350-ton reactor, flanked by the generator and service buildings



UNITED STATES The core cavity liner goes into the 75 MW sodium-graphite Hallam nuclear power facility in Nebraska

the coming on power shortly of EDF–1, would seem to imply that it will be plutonium.

The installation of the site as now planned will be completed by a swimming-pool reactor Pégase.

The CEA are also interested in developing a heavy water-moderated power-producing reactor for the next round of EDF stations. A large reactor experiment of 100 MWe capacity, EL–4, is to be built, and will probably use oxide fuel. A plant with a potential annual output of 25 metric tons of slightly enriched oxide fuel is now in production at Saclay; it took only six months to build.

WEST GERMANY

THE REVISED West German power reactor programme announced in March 1959 incorporates the earlier plan for 500 MW of German designed prototypes to be completed by 1965. They are (1) gas cooled graphite-moderated natural uranium, (2) heavy water-moderated and cooled natural uranium, (3) light water-moderated and cooled slightly enriched uranium, (4) high temperature gas-cooled enriched uranium, and (5) organic liquid-cooled and probably moderated, to be developed in collaboration with a US firm. The programme also includes two power stations of foreign design to be imported or built under licence by 1965, if required on economic or technical grounds. Also the development and provision of ancillary plant and materials e.g. fuel element manufacturing plant and canning materials is to be undertaken.

This is a very ambitious programme on the time scale proposed and will involve heavy expenditure and concentration of effort. Main responsibility for its completion has been firmly placed in the hands of German industry and power utilities, with financial assistance from the Federal Government. So far four groups of power companies and two individual utilities are considering the provision of power reactors.

Three design contracts awarded

In the 500 MW programme three design contracts for large power reactors have now been awarded, viz. a 100 MW heavy water power reactor study awarded by Atomkraft Bayern to Siemens-Schuckert ; a 100 MW gas–cooled, graphite-moderated reactor by the SKW group, Hanover to Deutsche Babcock and Wilcox ; and a 100 MW light water-moderated reactor also by SKW to AEG. Lastly, following the completion of the design study, construction is about to start on a 15 MW pilot plant high temperature reactor at Julich by Brown Boveri & Krupp for the AVR group for completion in 1962. It is to be followed by a full scale reactor.

Reactors of foreign design include the 15 MW boiling water reactor under construction at Kahl by AEG and GEC (US) for RWE and Bayernwerke. Two proposals for 150 MW stations have been under consideration under the US/Euratom joint programme, i.e. from the AKS group, Stuttgart and the BEWAG company in West Berlin. In addition, a collaboration and licensing agreement has been signed between MAN and the GEC (UK) on the advanced gas-cooled reactor.

A site for a 250 MW nuclear power station has been acquired near Augsburg by RWE but their present intention is to delay purchase until nuclear power is economic.

The cost target for competitive nuclear power in West Germany has until recently been 4 pfennig (0·8d a kWh) but with the prospect of the easier conventional supply position the figure is now about 3·8 pfennig (0·75d) a kWh or lower. These figures apply to areas mainly away from the coalfields, e.g. in central and south Germany and the Hamburg-Hanover area. The large and growing base load and considerable interconnexion are factors favourable to nuclear power. The expansion of the electricity supply industry may be expected to continue—output has risen at over 10% per annum since 1953 and total generating capacity as now reached about 24,000 MW. On the other hand, high capital charges at between 10 and 14% are less favourable than in some countries.

Present indications are that the short-term power reactor development programme will not be completed on time : the easier conventional energy position and the realization of the high cost of development have clearly caused some postponement. Because of the conventional fuel position, however, West Germany can afford to spread development over a fairly long time scale. On the other hand the long-term target of 6000 MW of nuclear generating capacity by 1975 is comparatively modest and may well be met.

EAST GERMANY

THE first nuclear power station will be a PWR situated at Neu Globsow, on the Gransee, and is now planned to be in operation in 1960. There is some doubt as to its capacity ; it seems likely that it is in the region of 70 MWe, though it might be higher. The conventional equipment is being manufactured in East Germany, and nuclear components are coming from the USSR.

The design of the station is said to be broadly similar to the Russian one at Voronezh, though about one third the size. It is interesting to speculate why this size was chosen : bearing in mind the economies of scale of pressure ves-

sels, there would presumably have been a strong incentive to build a larger station. It is possible that the demand for electricity was insufficient, but the answer might well be, though, that it was not possible to transport a larger pressure vessel from the Soviet Union ; the diameter of the Russian pressure vessel was determined by what the railways could carry.

HUNGARY

A 2 MWt research reactor supplied from the Soviet Union is now working at Czilleberg, Budapest ; it is light water-moderated and fuelled by 10% U–235. Hungary's increasing energy needs are at present largely met by imports of crude oil from the USSR but this is only regarded as a temporary solution and thoughts are turning towards the ultimate need for nuclear power.

ITALY

THERE ARE now three nuclear power stations either under construction or on order—the 200 MW gas-cooled graphite-moderated reactor at Latina, near Rome ; the 150 MW boiling water reactor at Punta Fiume, near Naples ; and the 160 MW pressurized water reactor to be sited near Milan. It is hoped to complete all three stations by 1963. With a total of about 500 MW, they constitute a major nuclear power constructional programme. All three stations are being built by foreign principal contracting firms, the first by the UK and the other two by the US, but in each case Italian firms are undertaking some of the work, e.g. some of the civil engineering.

The early decision to import full scale nuclear power stations rather than wait until Italian industry was ready to design and build all or the major part was conditioned partly by a wish to learn from other countries' experience but also on account of Italy's energy situation. The lack of indigenous fuel, especially coal, has long been an important factor in the development of the national economy, especially the development of light industry. Total energy consumption, which has reached about 50 M tons coal equivalent, is still small compared with the UK, West Germany and France. The predicted rise to 63 M tons in 1965 and 83 M tons in 1975 will necessitate the full development of Italy's main indigenous source of energy, i.e. hydro-electricity situated mainly in the Alps and Apennines, and also of her recent discoveries of oil and natural gas. Nuclear power offers promise as the alternative to still further imports of coal and oil.

Generating capacity in Italy now totalling 17,000 MW is carried out mainly by private or semi-Government owned supply utilities. Five companies have now been set up to operate nuclear power stations. AGIP-Nucleare, set up by the Government controlled ENI group, now has the Latina station under construction by the Nuclear Power Plant Co. of the UK. It will be operated by the subsidiary company SIMEA (Società Italiana Meridionale per l'Energia Atomica). AGIP-Nucleare also has an agreement with the NPPC on the supply of information on the design and construction of reactors ; in addition, it is considering the installation of a pressurized water reactor in North Italy. The second company to award a contract is SENN (Società Elettronucleare Nazionale), for whom the US General Electric Company are constructing the station at Punta Fiume. In September, 1959, the International Bank approved a $M40 loan towards the cost of the project. It is hoped to obtain fuel under the US/Euratom programme. SELNI (Società Elettronucleare Italiana) have been granted a credit of $M34 towards the cost of their proposed station near Milan ; the principal contractor will be Westinghouse Electric Corporation. Lastly SORIN (Società Ricerche Impianti Nucleari), founded by the Fiat and Montecatini groups, are considering the installation of two 150 MW stations. Recently, the five nuclear power companies set up a joint committee, which will provide a useful measure of co-ordination of the development of nuclear power in Italy.

Research considerable

In the meantime, Italy is building up nuclear research facilities and is now undertaking a considerable programme of work. A 5 MW CP–5 reactor and 1 MW swimming pool type are in operation and two further research reactors are under construction. The research centre at Ispra has already reached considerable size. An agreement has been reached for its lease to Euratom, though this has yet to be ratified by the Italian legislature.

No firm nuclear power programme has been decided although various targets have been proposed. This is partly due to the diversified structure of the electricity supply industry but is also increasingly due to a wish to await further information on comparative costs of nuclear and conventional power, especially the costs of the power reactors under construction. Nuclear generation in Italy is very sensitive to capital costs because of high capital charges at about 14%. About two years ago, average hydro and thermal generation costs were about 10 lire (1·4d) per kWh. At the present time, however, low freight rates have reduced the cost of imported US coal to about £5 a ton and modern coal fired plant in operation in about 1962 is now expected to provide power at under 8 lire (1·0d) a kWh. Hydro construction costs stand now at about £130 a kW.

THE NETHERLANDS

THE NUCLEAR power evaluation committee set up in 1958 by the SEP (an association of ten leading provincial and municipal power utilities), having examined ten designs for a 150 MW station provided by UK, US, and French firms, reported against the construction of a nuclear generating station at the present time, mainly on economic grounds. However, the SEP have reconsidered this decision more recently and may be expected to keep open the possibility of including a proposal for the installation of a 150 MW reactor under the US/Euratom joint programme. Estimated conventional generating costs in the near future are in the region of 3 cts. (0·75d) a kWh in contrast with 4·4 cts. (1·1d) a kWh for nuclear power given in the 1958 government paper.

The installation of a 150 MW nuclear power station was considered by the Limburg Electricity Co. as a joint project with the Interescaut Co. of Belgium, to be built at Mol, Belgium, but this proposal has now been abandoned.

It is almost certain that the 1965 target of 400 MW nuclear capacity proposed in the 1958 government paper will not now be achieved, but this appears to be only a temporary post-

RUSSIA Now at sea, the 'Lenin' ice-breaker is the first of the world's nuclear-powered ships. It is propelled by three pressurized-water reactors

ponement in the programme. In the meantime, the nuclear research effort is going steadily ahead at the major Netherlands research centres and in the joint programme with Norway. The research station at Petten, with its 20–30 MW materials testing reactor to come into operation in 1960, is being leased to Euratom.

Among various factors affecting the early provision of nuclear power in the Netherlands is the difficulty of accommodating a station larger than 150 MW in the transmission system. Furthermore, because of the density of population and small area of the country, safety, insurance and waste disposal are considered particularly important problems.

NORWAY

A MAJOR undertaking by Norway was the design and construction of the 20 MW experimental heavy water-moderated natural-uranium boiling water reactor at Halden. The reactor went critical in June 1959 and after a period of research will provide process steam for a nearby wood pulp factory. Fuel for the first charge was provided by the UK and last year the reactor became a joint ENEA project. The second charge (enriched) has now been ordered from Atomenergie AB of Sweden.

The next major step in the programme will be the provision of an isotope production and fuel element testing reactor but no plans exist at present for the installation of a power reactor.

POLAND

THE first Polish research reactor, Ewa, was supplied by the Soviet Union. This is of the standard USSR export type (2 MWt swimming pool). It is now running regularly for about 65 hours a week at the research centre of the Institute for Nuclear Research, at Swierk, near Otwock, 15 km outside Warsaw.

The next research reactor will be more directly applicable to Polish needs in that it will be graphite moderated and possibly hydrogen cooled ; however, this coolant is known to pose engineering problems. There is some discussion as to whether the fuel is to be enriched and, if so, to what extent. Poland must for the time being necessarily depend heavily on Soviet aid ; it now appears that there is some pressure on them to use enriched uranium, which would be in line with Soviet power station practice, rather than the natural uranium they would prefer. A joint materials testing reactor project with East Germany, and possibly Czechoslovakia, has been suggested as an alternative.

Long term plans for natural uranium power reactors remain at 200 MW by 1965, leading to 1800 MW total by 1975.

PORTUGAL

IT IS BELIEVED that hydro resources will be broadly sufficient to meet estimated demand until about 1975. Consideration has been given to the installation of a 100 MW nuclear power station near Lisbon but it was stated some time ago that there was no intention to acquire a station before 1965 and it would now seem that it will be further delayed. In addition to its activities in coordinating the development of nuclear power, the Junta de Energia Nuclear has the responsibility for carrying out research. It is building up a research centre near Lisbon and its first reactor, a 1 MW pool-type supplied by AMF Atomics, went into operation in 1959.

SPAIN

THE COMPLETION of the 3 MW pool reactor, provided by the US General Electric Company, at the research establishment at Moncloa is planned to be followed by a 20–30 MW intermediate reactor, providing combined facilities for isotope production, fuel element testing and power production. The third stage would be the completion of a large power reactor by 1965. The electricity supply industry in Spain is owned by private companies, and so far, three groups of producers, together with industry and financial institutions, are giving active thought to the eventual provision of nuclear power stations.

SWEDEN

DURING 1959 there has been much discussion on the date when the first large power reactors should be in operation. The State Power Board, the largest producer (about 50%) of electricity in Sweden, has dropped its plan to buy from the UK or US. The other organization considering the introduction of a nuclear power station is Atomkraftkonsortiet, which was set up by private power producers and industry, and has in the past stated that it plans to have a major power reactor in operation by 1965. AKK already has authority to operate a 60 MWe station — its constituent firms have smaller hydro electric reserves than the State Power Board. Recently it has been reported that the State Power Board and AKK are now considering collaboration through the joint construction of a 50 MWe US designed BWR reactor built under licence in Sweden. Government consent for this has apparently not yet been secured.

SWITZERLAND

THERE are now three reactor projects in hand in Switzerland. The government subsidized centre, run by Reaktor AG, at Würenlingen already contains the 1955 Geneva Conference swimming pool reactor. Its second reactor Diorit is due to go critical very shortly. It will have initially a capacity of 12·5 MWt. The fuel is natural uranium, and the moderator heavy water.

The Federal Government also has a substantial holding in Energie Nucléaire SA, of Lausanne. Plans there are to start building a 5 MWe BWR for completion by the end of 1963 ; this will be at Luceny, in Canton Vaud. The cost is high—about £600 per kWe—but it is thought necessary to pay this price to get the first hand knowledge necessary if French Switzerland is to be in a position to make and sell reactors in later years.

The same idea lies behind the reactor project, Suisatom, of Zürich, which will also be a BWR, 16 MWe, of US General Electric Company design. It is to be built by a powerful Swiss consortium—Brown Boveri, Escher Wyss, Oerlikon, and Sulzer. A 10% share is owned by Swiss Railways who have also undertaken to buy power from it. The station will be built near Villigen, on the river Aare, starting early 1960, and is due to go critical in the first half of 1963. In view of the fact that the object of present schemes is to train Swiss scientists and engineers in new techniques it is perhaps surprising that two of the reactors to be built will both be BWRS.

UNITED KINGDOM

THE FIVE nuclear power stations with a total output of 1875 MW now under construction in the UK at a cost of about £M250, constitute by far the largest constructional programme of nuclear generating capacity at present being undertaken in any country in the world. Together with the 300 MW of generating capacity of the plutonium production reactors at Calder Hall and Chapelcross, these five stations will produce electricity equivalent to about 6M tons of coal a year when all are completed. Thenceforward, nuclear power can be expected to provide in-increasing quantities of energy for the national economy. During the past year or so, it has become much more apparent that the rate of installation of nuclear generating capacity in the short term, say to 1970, will be dependent on trends in conventional power costs: but in the long term, it clearly remains an important and very necessary addition to conventional energy supplies, offering the prospects of costs falling well below those of conventional power.

During the past year or so, the prospect for supplies of conventional fuels has greatly improved. For the first time since World War II unwanted stocks of coal have been accumulating in the UK, as in other European countries. There have been a number of factors at work: oil consumption, for

POWER REACTORS AND PI

	NAME and or OWNER	STATUS and FIRST LOADING	LOCATION	PRINCIPAL CONTRACTOR	NET OUTPUT MWe	FUEL type (enrichm form, cladd
GRAPHITE	APS-1	O '54	Moscow (Obninsk)		5	U alloy (up to 5 tube, S.S.
	CALDER HALL A & B (UKAEA)	O '56–'58	Sellafield, England	—	140(4)	nat U, rod, Ma
	CHAPELCROSS A & B (UKAEA)	O, C '59, '60	Annan, Scotland	—	140(4)	nat U, rod, Ma
	G-2, G-3 (CEA)	O '58, '59	Marcoule, France	—	54(2)	nat U, rod, Mg
	SIBERIAN power station	O, C '58, '60	Troitsk, USSR		600(6)	nat U, rod, Al a
	EDF-1 (Electricité de France)	C '60	Chinon, France		70	nat U, hollow c Mg alloy
	BERKELEY (CEGB)	C mid '61	Berkeley, England	AEI—JT	275(2)	nat U, rod, Ma
	BRADWELL (CEGB)	C mid '61	Bradwell, England	NPPC	300(2)	nat U, rod, Ma
	HUNTERSTON (SSEB)	C June '62	Ardrossan, Scotland	GEC/SC	300(2)	nat U, rod, Ma
	HINKLEY POINT (CEGB)	C mid '62	Bridgwater, England	E E	500(2)	nat U, rod, Ma
	TRAWSFYNYDD (CEGB)	C '63	Trawsfynydd, Wales	APC	500(2)	nat U, rod, Ma
	AGR—Advanced Gas-Cooled Reactor (UKAEA)	C early '61	Windscale, England	—	28	UO_2 (1·25%), pe
	EDF-2 (Electricite de France)	C '61	Chinon, France		195	nat U, rod, Mg
	BELOYARSK power station	C '61	Urals (Beloyarsk)		100	U (1·3%), S.S.
	LATINA power station (SIMEA)	C '62	Latina, Italy	NPP/AGIP	200	nat U, rod, Ma
	HALLAM nuclear power facility (AEC & Consumers' Public Power District)	C '63	Hallam, Nebraska	AI	75	U/Mo (3%), ro
	JAPAN GCR (Japanese Atomic Power Co.)	P '62	Tokai Mura, Japan	GEC/SC	150	nat U, tubes, M
	VOLGA Centre station	P	Ulyanovsk, USSR		50	
	HTGR (AEC)	P '63	USA	HTRDA	40	U 255-Th/C
PWR	APPR—Army Package Power Reactor (US Army)	O April '57	Fort Belvoir, Va	Alco	2	UO_2/S.S. alloy (plates, S.S.
	SHIPPINGPORT (AEC & Duquesne Light Co)	O Dec '57	Shippingport, Pa	West	60	seed: U/Zr allo plates, Zircaloy blan: UO_2 (nat
	VORONEZH station	C '60	Voronezh, USSR		196	UO_2 (1·5%) pel
	BTR—Belgian Thermal Reactor (CEN)	C late '60	Mol, Belgium	West	11·5	UO_2 (4·5%), S.
	PM-1 (AEC & US Army)	C '60	Sundance, Wyoming	Martin	1	UO_2, tubes, S.
	GERMAN DEMOCRATIC REPUBLIC	C '60	Rheinsberg	USSR	70	
	CONSOLIDATED EDISON THORIUM REACTOR	C '61	Indian Point, NY	B & W	255	UO_2/ThO_2 (> S.S.
	YANKEE ATOMIC Electric Co.	C '61	Rowe, Mass	West	110	UO_2 (3%) pelle
	GENERAL PUBLIC UTILITIES CORP.	C '61	Saxton, Pa	West	5	UO_2 S.S.
	ENRICO FERMI project (SELNI)	C '63	N. Italy	West	160	UO_2 (2·7%) S.
	ML-1 (AEC & US Army)	P		Aerojet	0·45	UO_2, press-tub
BWR	VBWR—Vallecitos Boiling Water Reactor (GE & Pacific Gas & Electric Co)	O Aug '57	Pleasanton, Calif	GE	10	UO_2 (>90%),
	DRESDEN (Commonwealth Edison)	O late '59	Morris, Ill	GE	180	UO_2 (1·5%), ro
	RWE—Rheinisch-Westfälisches Electrizitätswerk	C '60	Kahl, Germany	AEG-GE	15	UO_2 (2·6%), r
	VOLGA Centre reactor	C '61	Ulyanovsk, USSR		50	UO_2 (1·5%), 2
	RURAL COOPERATIVE Power Assn & AEC	C '61	Elk River, Minn	ACF	22·2	Th/UO_2 (93%)
	JAPAN BWR (Japanese Atomic Energy Research Inst.)	C '61	Tokai Mura, Japan	GE	12·5	UO_2
	NORTHERN STATES Power Co	P '62	Sioux Falls, S. Dak	A-C	61·5	UO_2 (1·6%), pl
	SANTA LUCIA power station (BANDES)	P? '62	Santa Lucia, Cuba	Mitchell AMF, GNE	22	UO_2(3%), pell
	CONSUMERS POWER CO.	P '62	Big Rock Point, Michigan	GE	50	UO_2 (slight), pe
	PACIFIC GAS & Electric Co	P '62	Humboldt Bay, Calif	GE	50	UO_2 (1·9%), pe Zircaloy-2
	PROJECT ENSI—Energia Nucleare Sud Italia (SENN)	P '62	Punta Fiume, Italy	GE	150	UO_2 (2%), Zr
D_2O	RIII/ADAM (State Power Board, Stockholm)	C '62	Nr Stockholm, Sweden	ASEA/Atomic Energy Co	11e 55t	UO_2, pellets, 2
	CAROLINAS-VIRGINIA Nuclear Power Associates	P '62	Parr Shoals, DC	West	17	UO_2 (2%), rod,
	CZEC.. station	C '63	Bohunice, Czechoslovakia		150	nat U, rod, Be

D PROTOTYPES

FUEL type (enrichment) form, cladding	COOLANT type, pressure (psia) temp (deg C) flow (lb/min)	NOTES
U alloy (up to 5%), press. tube, S.S.	H_2O, 1420, 190	has operated boiling
nat U, rod, Magnox	CO_2, 115, 333 (ex), 33,300	all critical, Pu prod
nat U, rod, Magnox	CO_2, 115, 333 (ex), 33,300	2 critical, Pu prod
nat U, rod, Mg-Zr alloy	CO_2, 210, 350 (ex), 100,000	Pu prod
nat U, rod, Al alloy	H_2O	1 critical, Pu prod
nat U, hollow cylinder, Mg alloy	CO_2, 350, 355 (ex), 167,000	Pu prod
nat U, rod, Magnox	CO_2, 140, 345 (ex), 381,000	3 further stations planned: Dungeness (500), Sizewell (850), Oldbury-on-Severn (1000)
nat U, rod, Magnox	CO_2, 147, 390 (ex)	
nat U, rod, Magnox	CO_2, 165, 391 (ex), 354,000	
nat U, rod, Magnox	CO_2, 200, 375 (ex), 600,000	
nat U, rod, Magnox	CO_2, 255,399 (ex) 540,000	
UO_2 (1·25%), pellets, Be	CO_2, 285, 575 (ex)	
nat U, rod, Mg alloy	CO_2, 350, 355 (ex), 167,000	no containment vessel
U (1·3%), S.S. press. tubes	boiling H_2O, 2100, 355 superheat 1420, 530	nuclear superheat
nat U, rod, Magnox	CO_2, 197, 390 (ex)	
U/Mo (3%), rod S.S.	Na, 61, 507 (ex), 15,450 gpm Na, 73, 477 (ex), 14,352 gpm	Specially designed to withstand earthquakes
nat U, tubes, Magnox	CO_2, 220,398 (ex) 360,000	
	Na, 1280, 500 (ex)	
U 255-Th/C	He,—, 1000	General Dynamics design
UO_2/S.S. alloy (highly), plates, S.S.	H_2O, 1215, 235 (ex), 27,000	APPR-1a—twice thermal output—to be installed in Alaska by '60
seed: U/Zr alloy (90%) plates, Zircaloy-2 blan: UO_2 (nat), Zircaloy-2	H_2O, 2000, 272 (av), 377,000	with 2nd core 100 MW
UO_2 (1·5%) pellets, Zr	H_2O, 1420, 275, 1,000,000	
UO_2 (4·5%), S.S.	H_2O, 2000, 268(ex), 82,000	two-region core
UO_2, tubes S.S.	H_2O, 1300, 240 (av)	suitable for air transportation
UO_2/ThO_2 (>90%) pellets, S.S.	H_2O, 1515, 270 (ex), 900,000	includes oil superheat 104 MW
UO_2 (3%) pellets, S.S.	H_2O, 2000, 268 (av), 635,000	with 2nd core to 135 MW
UO_2 S.S.	H_2O	
UO_2 (2·7%) S.S.	H_2O	later up to 225 MW
UO_2, press-tubes	N_2,—, 650 (ex)	suitable for air transportation
UO_2 (>90%), plates, S.S.	H_2O, 1015, 282 (ex), 1330	direct cycle
UO_2 (1·5%), rods, Zircaloy-2	H_2O, 1042, 285 (ex), 427,000	
UO_2 (2·6%), rods, Zircaloy-2	H_2O, 1000, 285 (ex), 4200	later up to 30MW
UO_2 (1·5%), Zr	H_2O	direct cycle, similar elements to PWR
Th/UO_2 (93%), pellets, S.S.	H_2O, 952, 280 (ex), 16,300	includes superheat 16MWe
UO_2		also R & D for ship propulsion
UO_2 (1·6%), plates, Al alloy	H_2O, 615, 255 (ex)	controlled recirculation; superheat (prob. nuclear) 16 MWt
UO_2 (3%), pellets, S.S.	H_2O	oil-fired superheat
UO_2 (slight), pellets, Zr	H_2O, 1450	direct cycle, later 75 MW
UO_2 (1·9%), pellets, Zircaloy-2	H_2O, 1015, 286 (ex), 174,000	
UO_2 (2%), Zr	H_2O, 1015, 286	
UO_2, pellets, Zircaloy-2	D_2O, 495, 220 (ex), 132,000	70 MWt for district heating
UO_2 (2%), rod, Zircaloy-2	D_2O, 1500, 301 (ex), 55,800	pressurized D_2O; prototype for 200 MW plant
nat U, rod, Be-Mg	CO_2, 850, 425 (ex), 210,000	

HIGH

	NAME and/or OWNER	STATUS and FIRST LOADING		LOCATIO
D_2O	NRX (AECL)	O	'47	Chalk River,
	NRU (AECL)	O	'57	Chalk River,
	EL-3 (CEA)	O	'57	Saclay, Franc
	DIDO (UKAEA)	O	'56	Harwell, Engl
	HIFAR—High Flux Australian Reactor (AAEC)	O	'58	Lucas Height
	NORTH RHINE—Westphalia	C	'61	Julich, Germa
	PLUTO (UKAEA)	O	'57	Harwell, Engl
	DMTR—Dounreay Materials Testing Reactor (UKAEA)	O	'58	Dounreay, Sc
	DR-3—Danish Reactor	C	'60	Riso, Denmar
	CHINA—Institute of Atomic Energy	O	'58	Peking, Chin
	JRR-2—Japanese Research Reactor 2	C	'59	Tokai Mura,
	CIR—Canada India Reactor	C	'60	Trombay, Ind
	FR-2 (Kernreaktor Bau-und-Betriebs GmbH)	C	'60	Kahlsruhe, G
	JRR-3—Japanese Research Reactor 3	P	'61	Tokai Mura,
	BROOKHAVEN High Flux Beam Research Reactor	P	'62	Upton, NY
TANK	MTR—Materials Testing Reactor (AEC)	O	'52	NRTS, Idaho
	ETR—Engineering Test Reactor (AEC)	O	'57	NRTS, Idaho
	ORR—Oak Ridge Research Reactor (AEC)	O	'58	Oak Ridge, T
	GETR (General Electric Co)	O	'58	Pleasanton, C
	WTR—Westinghouse Test Reactor	O	'59	Waltz Mill, P
	R-2 (AB Atomenergi)	C	'60	Studsvik, Swe
	WWR-M (USSR)	C	'59	Nr Leningrad
	WWR-Z (USSR)	C		
	HFR (Reactor Centrum Nederland)	C	'59	Petten, Neth
	NASA-TR (National Aeronautics and Space Administration)	C	'59	Sandusky, O
	BR-2—Belgian CEN	C	'60	Mol, Belgium
	ITR (Industrial Testing Reactors Inc)	P	'60	Wadesboro,
	INTERMEDIATE energy reactor	C	'61	Moscow(?),
	JAPAN MTR	P	'63	Tokai Mura,
GRAPHITE	BEPO (UKAEA)	O	'48	Harwell, Eng
	BROOKHAVEN Research Reactor (AEC)	O	'50	Upton, NY
	RFT (Institute of Physics, Moscow)	O	'52	Moscow, US
	ANTR—Aerojet Nuclear Test Reactor	P	'60	San Ramon,

IGH POWER RESEARCH REACTORS

LOCATION	PRINCIPAL CONTRACTOR	THERMAL OUTPUT MW	MAX NEUTRON FLUX	FUEL type (enrichment) form, cladding	REFLECTOR	COOLANT	NOTES
halk River, Canada		30	$6{\cdot}8 \times 10^{13}$	nat U, rod, Al	graphite	H_2O	original output 30 M
halk River, Canada		200	3×10^{14}	nat U, rod, Al	H_2O	D_2O	
aclay, France		15	10^{14}	U (highly)	D_2O & graphite	D_2O	
larwell, England	HWP	10	10^{14}	U/Al alloy plates (90%) Al	graphite	D_2O	
ucas Heights, Austr.	,,	,,	,,	,,	,,	,,	
ulich, Germany	,,	,,	,,	,,	,,	,,	
Harwell, England	HWP	10	10^{14}	U/Al alloy plates (90%) Al	graphite	D_2O	fewer, larger exp. hole than DIDO
Dounreay, Scotland	,,	,,	,,	,,	,,	,,	
Riso, Denmark	,,	,,	,,	,,	,,	,,	
Peking, China	USSR	10	6×10^{13}				Also in Belgrade
Tokai Mura, Japan	AMF	10	10^{14}	U (20%)			modification of CP-5
Trombay, India	Foundation	30	$6{\cdot}8 \times 10^{13}$				NRX type
Kahlsruhe, Germany	Owner	12		nat U, Th		D_2O	
Tokai Mura, Japan	Japanese design	10	10^{13}	nat U			
Upton, NY	BNL	20					
NRTS, Idaho	Fluor Corp	40	5×10^{14}	U/Al alloy plates (93%) Al	Be	H_2O	has operated on Pu
NRTS, Idaho	Kaiser	175	7×10^{14}	U/Al alloy (93%), plates, Al	Be	H_2O	
Oak Ridge, Tenn	ORNL	20–30	10^{14}	MTR type	Be	H_2O	Be-moderated
Pleasanton, Calif	Owner	30					
Waltz Mill, Pa	Owner	20					later to 60 MW
Studsvik, Sweden	ACF	30	$2{\cdot}4 \times 10^{14}$	U/Al alloy (20–90%)	Be, D_2O, H_2O	H_2O	ORR type
Nr Leningrad		10	10^{14}	UO_2/Al alloy (20%) tube, Al	Be	H_2O	
		10	10^{14}	UO_2/Al alloy (20%) tube, Al	Be & H_2O	H_2O	radiochemical researc fuel loading than WV
Petten, Netherlands	ACF	20	$2{\cdot}6 \times 10^{14}$	MTR type (90%)	Be	H_2O	modified ORR
Sandusky, Ohio	Owner	60					
Mol, Belgium	NDA	25	6×10^{14}	U/Al alloy (90%) tubes, Al	Be	H_2O	pressurized
Wadesboro, NC	GE	50					
Moscow(?), USSR			2×10^{13}	U (90%)	BeO	H_2O	
Tokai Mura, Japan		50		MTR type (90%)			
Harwell, England		6	10^{13}	nat U bars, Al	graphite	air	main British source o
Upton, NY	Ferguson	30	3×10^{13}	MTR type	graphite	air	
Moscow, USSR		15–20	$1{\cdot}8 \times 10^{14}$	UO_2/Al alloy (90%) tubes, Al	graphite & H_2O	H_2O	
San Ramon, Calif	AGN	10					

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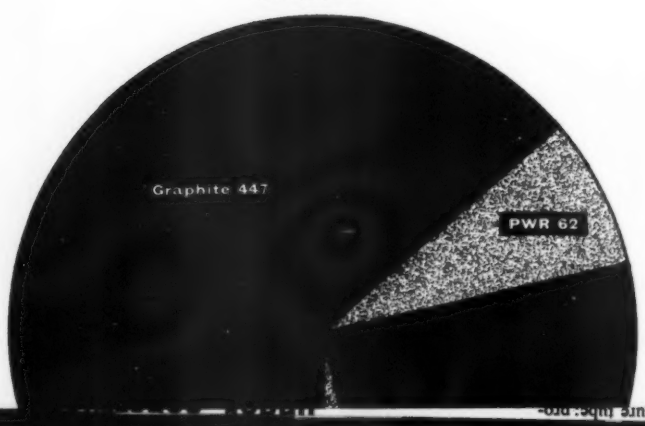

NOTES
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The World's React

Reactors have been classified by moderator and are shown as either in operation (O), under construction (C), or definitely planned (P)—design studies and projects are not included. Research reactors no longer in use and those built for a specific purpose have been omitted as have power reactors built for military use.

LOW POW

	NAME and or OWNER	STATUS and FIRST LOADING		LOCATION	PF CO
GRAPHITE	X-10 (AEC-ORNL)	O	'43	Oak Ridge, Tenn	Clin
	GLEEP—Graphite Low Energy Experimental Pile (UKAEA)	O	'47	Harwell, England	
	BR-1 (CEN)	O	'56	Mol, Belgium	CE
	ARGONAUT (AEC)	O	'57	Lemont, Ill	AN
	NERO	O	'57	Harwell, England	
	UTR-10 (American Radiator and Standard Sanitary Corp)	O	'58	Mountain View, Calif	Ow
	JASON (Hawker Siddeley Nuclear Power Co Ltd)	O	'59	Slough, England	Ow
	ZENITH (UKAEA)	C	'60	Winfrith Heath, England	GE
	FLORIDA University	C		Gainesville, Fla	GN
	AMF-GNE Educator				AM
POOL	SAPHIR	O	'55	Würenlingen, Switz	OR Rea
	PENNSYLVANIA State University	O	'55	University Park, Pa	Ow
	NRR—Naval Research Reactor (USN)	O	'56	Washington, DC	NR
	APSARA (AEC of India)	O	'56	Trombay, India	Ow
	LIDO (UKAEA)	O	'56	Harwell, England	Vic
	FORD Nuclear Reactor (Univ of Michigan)	O	57	Ann Arbor, Mich	B &
	HOR (Delft Technical University)	O	'57	Delft, Netherlands	AM
	PTR—Pool Test Reactor (AECL)	O	'57	Chalk River, Canada	Can
	ITR (USSR Academy of Sciences)	O	'57	Moscow, USSR	
	NEPTUNE (UK Admiralty)	O	'57	Harwell, England	Vic
	SAO PAULO University	O	'57	Sao Paulo, Brazil	B &
	FRH (German Society for Utilization of Nuclear Energy in Shipbuilding & Navigation)	O	'58	Nr Hamburg, Germany	,
	PISA University	C	'60	Pisa, Italy	,
	EWA (Polish Institute for Nuclear Research)	O	'58	Nr Warsaw, Poland	US
	MELUSINE (CEA)	O	'58	Grenoble, France	CE
	TRITON (CEA)	C	'59	Fontenay aux Roses, France	Ind
	AMF 1 MW tank	O	'56	Battelle Memorial Institute, Ohio	Ow
	AMF 5 MW tank	O	'59	Plainsboro, NJ	Ow

Collective Totals

high temp pressure tube; pro

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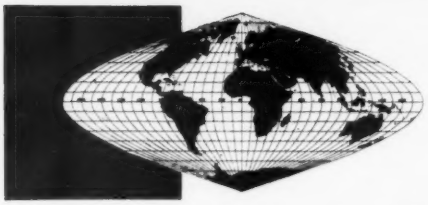

JANUARY 1960

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POWER REACTORS: output is from one reactor unless otherwise stated in brackets; coolant temperatures are mainly average in the core unless given as exit values.

RESEARCH REACTORS: high power reactors are defined as those over 5000 kWt; neutron fluxes are in n/cm²/s and are for thermal neutrons except in the case of fast reactors.

LOW POWER RESEARCH REACTORS

LOCATION	PRINCIPAL CONTRACTOR	THERMAL OUTPUT kW	MAX NEUTRON FLUX	FUEL type (enrichment) form, cladding	REFLECTOR	COOLANT	NOTES
Oak Ridge, Tenn	Clinton Lab	3800	$1{\cdot}12 \times 10^{13}$	nat U, rod, Al	graphite	air	
Harwell, England		10	$3{\cdot}7 \times 10^{12}$	nat U bars & UO_2 pellets, Al	graphite	air	first in UK & still in use
Mol, Belgium	CEN/ACEC	4000	$2{\cdot}1 \times 10^{13}$	nat U, bars, Al	graphite	air	similar to X-10
Lemont, Ill	ANL	10		MTR type	graphite	H_2O	
Harwell, England		—	$\sim 10^{8}$	U (slightly)			
Mountain View, Calif	Owner	10	10^{11}	MTR type	graphite	H_2O	developed from Argonaut
Slough, England	Owner	10	$1{\cdot}5 \times 10^{13}$	MTR type	graphite	H_2O	Also Nestor at Harwell (P) Developed from Argonaut
Winfrith Heath, England	GEC	0·100	10^{8}	U/Th, pellets	graphite	N_2	for physics of HTGR's
Gainesville, Fla	GNE	10					
	AMF-GNE	10	10^{11}	U/Al alloy (20%), plates	graphite	H_2O	developed from Argonaut
Würenlingen, Switz	ORNL/ Reactor Ltd	1000	$\sim 10^{13}$	MTR type (20%)	H_2O	H_2O	1955 Geneva Conference re-built
University Park, Pa	Owner	100		MTR type	H_2O	H_2O	to be increased to 1000 kW 10^{13} flux
Washington, DC	NRL	100			H_2O	H_2O	
Trombay, India	Owner	1000		MTR type	H_2O	H_2O	
Harwell, England	Vickers	100	10^{13}	DIDO type	H_2O	H_2O	shielding experiments
Ann Arbor, Mich	B & W	1000			H_2O	H_2O	
Delft, Netherlands	AMF	100			H_2O	H_2O	originally on show at Het Atoom exhibition; then 10kW
Chalk River, Canada	Canadair	0·100t		U (90%), rod	H_2O	H_2O	
Moscow, USSR		2000	$3{\cdot}2 \times 10^{13}$	UO_2/Mg alloy (10%), rod, Al	H_2O	H_2O	similar reactors in Czechoslovakia, Rumania, Hungary & E. Germany
Harwell, England	Vickers	—	$\sim 10^{8}$	U (enr)	H_2O	H_2O	Pressurized water, marine studies
Sao Paulo, Brazil	B & W	5000		MTR type (20%)	H_2O	H_2O	
Nr Hamburg, Germany	"	"		"	"	"	four special-purpose pools, marine research
Pisa, Italy	"	"	"	"	"	"	
Nr Warsaw, Poland	USSR	2000		U (10%), Al	H_2O	H_2O	Also in Hungary, Rumania & Bulgaria
Grenoble, France	CEA, & Indatom	1200	10^{13}	U alloy plates (20%)	H_2O	H_2O	two working positions
Fontenay aux Roses, France	Indatom	1000	10^{13}	U alloy plates (20%)	H_2O	H_2O	
Battelle Memorial Institute, Ohio	Owner	1000	$6{\cdot}6 \times 10^{13}$	MTR type (20%)	H_2O	H_2O	19 sold, including Munich (O) Athens (C), Tel Aviv (C), Saluggia (O), Lisbon (C), Teheran (P), Mayaguez (C), Delft (P), Istanbul (P)
Plainsboro, NJ	Owner	5000		MTR type	H_2O	H_2O	Also at Stirling Forest, NY (C), Vienna (C)

D_2O	RIII/ADAM (State Power Board, Stockholm)	C	'62	Nr Stockholm, Sweden	ASEA/Atomic Energy Co	11e 55t	UO_2, pellets, Zircaloy-2	D_2O, 495, 220 (ex), 132,000	70 MV
	CAROLINAS-VIRGINIA Nuclear Power Associates	P	'62	Parr Shoals, DC	West	17	UO_2 (2%), rod, Zircaloy-2	D_2O, 1500, 301 (ex), 55,800	pressu for 200
	CZEC		'63	Bohunice, Czechoslovakia		150	nat U, rod, Be-Mg	CO_2, 850, 425 (ex), 210,000	
	EAST CENTRAL & FLORIDA WEST COAST Nuclear Power Groups	P	'63	Florida	GNE	50	U (slight)	gas	high te totype
	CANDU (AECL)	P	'64	Kincardine, S. Ont.		200	nat U	D_2O	based o
FAST	ENRICO FERMI (Power Reactor Dev Co)	C	Sep '60	Lagoona Beach, Mich	Owner	90	core: U-Mo alloy (27%), pins, Zr blan: U-238. Mo alloy, pins, S.S.	Na, 92, 425 (ex), 220,000 Na, 30, 397 (ex), 220,000	
	BR-50	P		Ulyanovsk, USSR		50	Pu	Na, —, 480 (av), 128,000	constr begin tion
OMR	CITY OF PIQUA & AEC	C	'61	Piqua, Ohio	AI	11·4	U (1·8%), 2 concentric tubes, Al	Terphenyl, 120 (max), 302 (ex), 92,000	

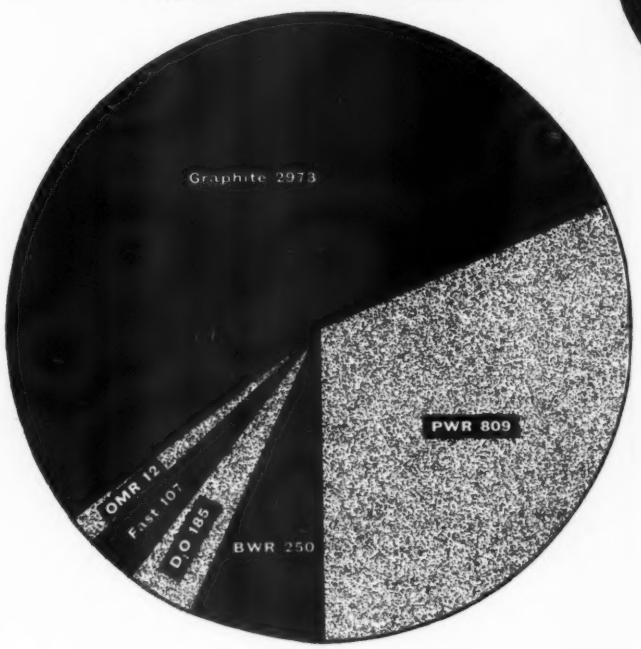
POWER REACTOR EXPERIMENTS

	NAME and or OWNER	STATUS and FIRST LOADING		LOCATION	PRINCIPAL CONTRACTOR	NET OUTPUT MWe or t	FUEL type (enrichment) form, cladding	COOLANT type, pressure (psia) temp (deg C) flow (lb/min)	
GRAPHITE	G-I (CEA)	O	'56	Mareoule, France	—	1·7e	nat U, rod, Mg	air, atm, 135, 12,700	Pu pro
	SRE—Sodium Reactor Experiment (AEC & S. Calif Edison Co.)	O	April '57	Santa Susana, Calif	AI	6e	U (2·8%), rod, S.S.	Na, 21, 515 (ex), 150	
	DRAGON—High Temp. Gas-cooled Reactor (UKAEA—ENEA)	P		Winfrith Heath, England		10t	U-235/Th,rod, graphite	He, 165, 750	
	LMFRE-1—Liquid Metal Fuelled Reactor Experiment (AEC)	P		Lynchburg, Va	B & W	5t			
	EPGCR-Experimental Prototype Gas-cooled Reactor (AEC)	P	'62	Oak Ridge, Tenn	KE-ACF	24e			
	AVR Kraftwerk	P	'63	Julich, Germany	Krupp/Brown Boveri	15e	UC (20%), spheres, graphite	He/Ne, —, 850	experie
	TURRET (LASL)	P		Los Alamos, N Mex	Sandia	3t	UNO_2/graphite tubes, none	He,—, 1300	
PWR	LENIN icebreaker (USSR)	O	'59	—		180t (2)	UO_2 (5%), Zr alloy or S.S.	H_2O, 2850, 325, 36,670	third re full pow total di
	PORTABLE Russian plant	C	'59	Moscow (Obninsk)		2e		H_2O, 1710	
	NS SAVANNAH passenger cargo vessel (AEC & Maritime Admin.)	C	'60	—	B & W	63t	UO_2 (4%), pellet, S.S.	H_2O, 1750, 265, 30,000	full pow total di
BWR	EBWR—Experimental Boiling Water (AEC)	O	Dec '56	Lemont, Ill	ANL	4·5e	U (1·44%), plate, Zircaloy-2	H_2O, 615, 255 (ex), 1,010	with 2r
	ALPR—Argonne Low Power (AEC)	O	'58	NRTS, Idaho	ANL	0·2e 4t	U/Al alloy (highly), plates, Al-Ni alloy	H_2O, 315, 215, 16,700	packag areas
	BORAX-5—Boiling Water Reactor Experiment (AEC)	P	'60	NRTS, Idaho	ANL	2e	ThO_2/UO_2, plate, Al-Ni alloy	H_2O,	direct 4 dism
	SUISATOM	P	'63	Villigen, Switzerland	GE	16			
	ENERGIA NUCLEAIRE SA	P	'63	Nr. Lausanne, Switzerland		5e	UO_2 (1·4%), Zr	H_2O, 482, 250	underg
D_2O	HALDEN (Institutt for Atomenergi and ENEA)	O	'59	Halden, Norway	IFA	20t	nat U; bar, Al	boiling D_2O, 570, 230	produc paper
	NPD-II—Nuclear Power Demonstration (AECL & Hydro Elec. Power Comm.)	C	'61	Des Joachims, Ont	Can. GE	19e	UO_2, Zr, pressure tubes	D_2O, 1115, 277 (ex), 86,000	dev. fr CAND
	SULZER project	P		Zurich, Switzerland	Sulzer Bros	30t	mostly nat U, Zircaloy, pressure tube	D_2O, 850, 220	electric underg
FAST	EBR-1—Experimental Breeder Reactor (AEC)	O	'51	NRTS, Idaho	ANL	0·2e	core: U alloy (93%), rod, S.S. blan: Nat U, S.S.	NaK, 28, 318 (ex), 2,030 NaK, 35, 305 (ex), 2,030	
	BR-5	O	'58	USSR		5e	core: PuO_2, S.S. blan: B-U alloy, S.S.	Na—450 (ex) 130 cu m/h NaK—430 (ex) 130 cu m/h	experie
	DFR Dounreay Fast Reactor (UKAEA)	O	'59	Dounreay, Scotland	—	15e	core: U (enr), tube, Nb & Va blan: nat U, rod, S.S.	NaK—350 (ex), 52,000 NaK—325 (ex), 52,000	change comm.
	LAMPRE-1—Los Alamos Molten Plutonium Reactor Experiment (AEC)	C	'60	Los Alamos, N Mex	LASL	1t	molten Pu		long-te
	EBR-2 (AEC)	C	'61	NRTS, Idaho	ANL	17e	core: U alloy (49%) pin S.S. blan: depleted U, pin, S.S.	Na, 72, 480 (ex), 58,000 Na, 78, 469 (ex), 43,000	
	RAPSODIE (CEA)	P	'62	Cadarache, France		10t	U-235 + Pu	Na	
HOMOG.	HRE-2—Homogeneous Reactor Experiment (AEC)	O	Dec '57	Oak Ridge, Tenn	ORNL	5t	UO_2SO_4/D_2O (>90%)	core: D_2O in soln., 1715, 300 (ex), 3,000 blan: D_2O, 1715, 283 (ex), 1,600	HRE-1
	LAPRE-2—Los Alamos Power Reactor Experiment (AEC)	O	'59	Los Alamos, N Mex	LASL	1t		UPO, (enr), HPO_3 & H_2O	LAPRE superhe
	VOLGA Centre	C		Ulyanovsk, USSR		35t	UO_2 in D_2O	D_2O	boiling
	HOMOGENEOUS SUSPENSION (Reactor Centrum Nederland)	C			KEMA	0·25e	UO_2 in H_2O		
	WALTER REED Army Medical Centre	C	'60	Washington	AI	50	UO_2SO_4/H_2O		for me treatme
OMR	OMRE—Organic Moderated Reactor Experiment (AEC)	O	'57	NRTS, Idaho	AI	5-15t	UO_2/S.S. alloy (highly), plates, S.S.	Terphenyl, 300, 275–375 (ex), 7.200 gpm	
	GKSS ship reactor	P	'63		Interatom				for tan dwt
B_2O	BRENDA (CEA)	P		Cadarache, France		10-17t	enr U	gas	

000	70 MWt for district heating
300	pressurized D_2O; prototype for 200 MW plant
000	
	high temp pressure tube; prototype for 200 MW station
	based on NPD-2
0	
0	
0	construction on BN-250 to begin when BN-50 in operation

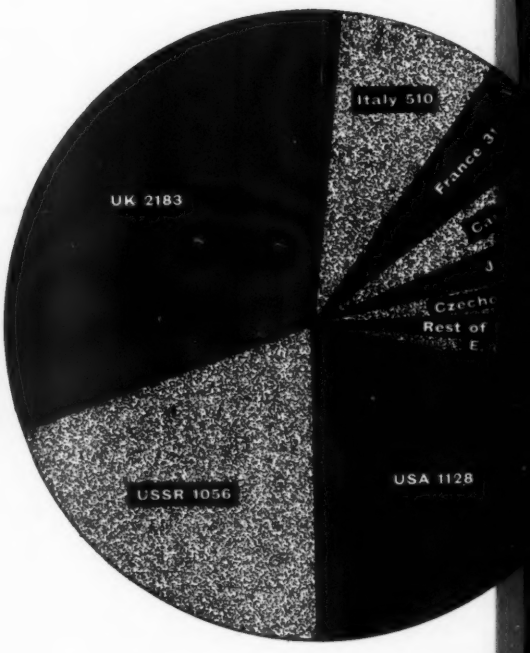
	NOTES
in)	
	Pu prod
	experience for 100MW plant
0	third reactor 90 MWt reserve; full power 44,000 h.p.; 3 props; total displacement 16,000 tons.
00	full power 22,000 h.p.; 1 prop; total displacement 21,840 tons.
,010	with 2nd core 100 MWt
0	packaged plant for remote areas
	direct cycle; Borax 1, 2, 3 & 4 dismantled
	underground
0	produces steam for local paper mills
86,000	dev. from NPD-1. Pilot for CANDU
	electricity or district heating; underground
030 030	
m/h u m/h	experience for BR-50
00 00	change to Na 18 months after comm.
	long-term project
00 00	
715,	HRE-1 dismantled 1954
3 (ex),	
H_2O	LAPRE-1 dismantled 1957 superheated steam direct
	boiling cycle
	for medical research and treatment
-375 (ex),	
	for tankers up to 40,000 tons dwt

under construction



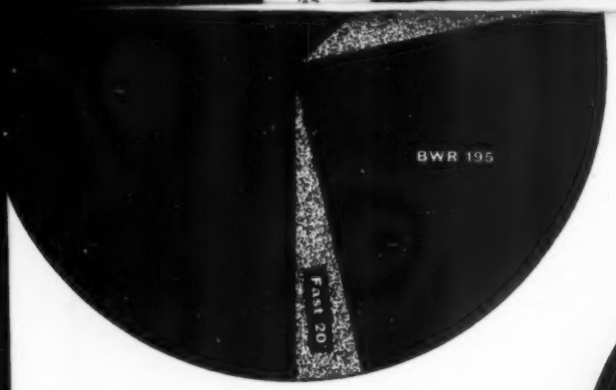
Total MWe

National programmes—MWe critical, under construction and definitely planned

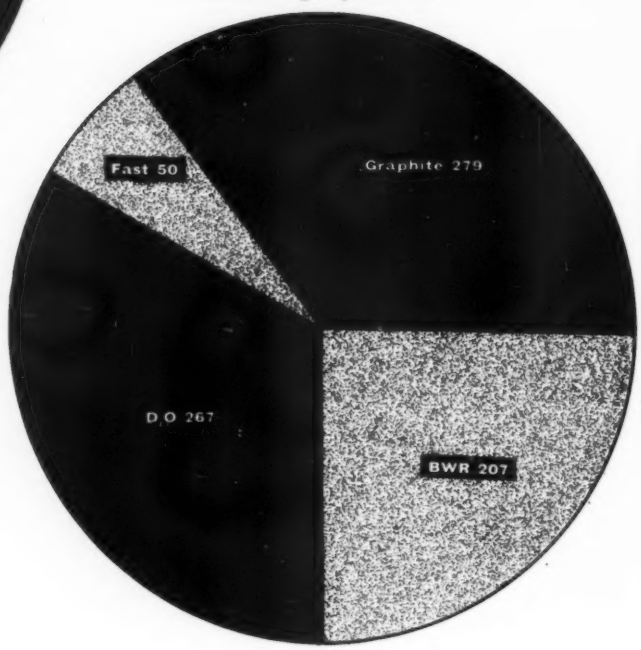


A-C—Allis Chalmers Mfg. Co.
ACEC—Ateliers de Constructions Electriques de Charleroi.
AEC—United States Atomic Energy Commission.
AECL—Atomic Energy of Canada Ltd.
AEG—Allgemeine Elektrizitäts Gesellschaft.
AEI-JT—AEI-John Thompson Nuclear Energy Co.
AGIP—Agip Nucleare.
AGN—Aerojet General Nucleonics.
AI—Atomics International.
AMF—AMF Atomics.
ANL—Argonne National Laboratory.
APC—Atomic Power Constructions Ltd.
BANDES—Cuban National Bank for Social and Economic Development.
BNL—Brookhaven National Laboratory.
B & W—Babcock & Wilcox Co. Ltd.

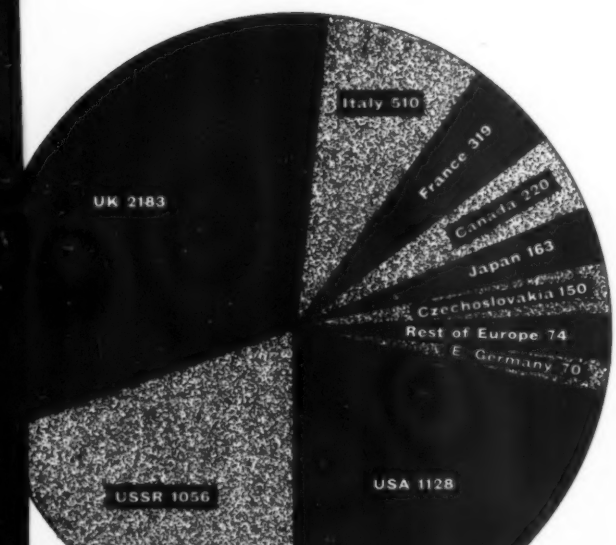
ABBR
CEA—Commissar
CEGB—Central E
CEN—Centre d'E
de l'Energie Nu
EE—English Elec
ENEA—European
FW—Foster Whe
GE—General Ele
GEC—The Gener
GKSS—Gesellsch
tung in Schiff
GNE—General N
HTRDA—High T
ment Associates
HWP—Head Wri
JENER—Joint
ment for Nucle
KE—Kaiser Engi



definitely planned



Total MWe



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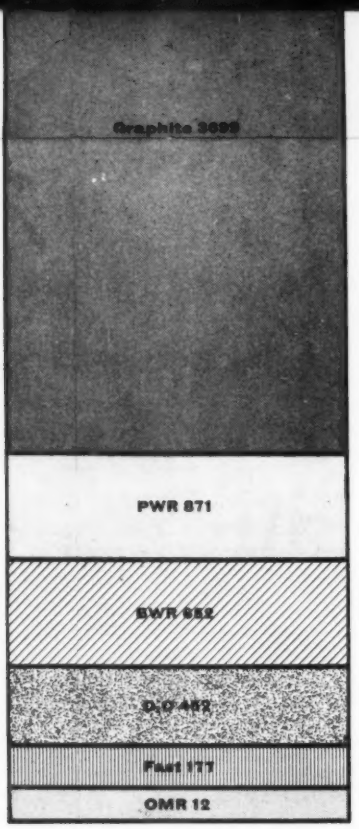
ABBREVIATIONS

...g. Co.
...nstructions Electriques
...Atomic Energy Com-
...of Canada Ltd.
...rizitäts Gesellschaft.
...mpson Nuclear Energy
... Nucleonics.
...al.
...l Laboratory.
...nstructions Ltd.
...onal Bank for Social
...oment.
...onal Laboratory.
...cox Co. Ltd.

CEA—Commissariat à l'Energie Atomique.
CEGB—Central Electricity Generating Board.
CEN—Centre d'Etudes pour les Applications de l'Energie Nucléaire.
EE—English Electric Co. Ltd.
ENEA—European Nuclear Energy Agency.
FW—Foster Wheeler Corp.
GE—General Electric Co. (of America).
GEC—The General Electric Co. Ltd.
GKSS—Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt mbH.
GNE—General Nuclear Engineering Co.
HTRDA—High Temperature Reactor Development Associates Inc.
HWP—Head Wrightson Processes.
JENER—Joint Dutch-Norwegian Establishment for Nuclear Energy Research.
KE—Kaiser Engineers.
LASL—Los Alamos Scientific Laboratory.
NDA—Nuclear Development Corporation of America.
NPPC—Nuclear Power Plant Co.
NRL—Naval Research Laboratory.
NRTS—National Research Testing Station.
ORNL—Oak Ridge National Laboratory.
SC—Simon-Carves Ltd.
SELNI—Società Elettronuclear Italiana.
SENN—Società Elettronucleare Nazionale.
SIMEA—Società Italiana Meriodionale Energia Atomica.
SORIN—Società Ricerche Impianti Nucleari.
SSEB—South of Scotland Electricity Board.
UKAEA—United Kingdom Atomic Energy Authority.
VICKERS—Vickers Nuclear Engineering Ltd.
VITRO—Vitro Engineering Co.
WEST—Westinghouse Electric Corp.



POOL	AMF 1 MW tank	O	'56	Battelle Memorial Institute, Ohio	Owner	1000	6·6 x 10
	AMF 5 MW tank	O	'59	Plainsboro, NJ	Owner	5000	
	SPANISH Nuclear Energy Board	O	'58	Nr Madrid, Spain	GE	3000	
	CURTIS-WRIGHT Corp	O	'58	Quehanna, Pa	Owner	1000	
	BABCOCK & WILCOX Atomic Energy Division	O	'58	Lynchburg, Va	Owner	10	
	MERLIN (AEI Ltd)	O	'59	Aldermaston, England	Owner	5000	5 x 10
D_2O	TAIWAN National Tsin-Hua University	C	'59	Taipei, Taiwan	GE	1000	
	WASHINGTON STATE College	C	'59	Pullman, Wash	,,	100	
	ORDNANCE MATERIALS Research Office	C	'59	Watertown, Mass	Owner	1000	
	CORNELL University	C	'59	Ithaca, NY	Vitro	10	
	VIRGINIA University	C	'60	Charlottesville, Va	Owner	1000	
	NORTH CAROLINA State College	C	'60	Raleigh, NC	Cook	10	
	ALIZE (CEA)	P	'60	Saclay, France	Caratom	—	
	AGN 211			Several under constr.	AGN	1-100 W	2·5 x 10
	AGN 451				AGN	1 or 100	10 or 1
D_2O	ZEEP—Zero Energy Experimental Pile (AECL)	O	'45	Chalk River, Canada		0·100	10
	EL-1 (ZOE) (CEA)	O	'48	Fontenay aux Roses, France		150	10
	TR (USSR)	O		Inst. of Heat Tech, USSR		2500	2·5 x 10
	JEEP (JENER—Dutch Norwegian Joint Establishment)	O	'51	Kjeller, Norway	Institutt for Atomenergi	500	2·2 x 10
	EL-2 (CEA)	O	'52	Saclay, France		2000	10
	CP-5 (AEC)	O	'54	Lemont, Ill	ANL	2000	~10
	R1 (AB Atomenergi)	O	'54	Stockholm, Sweden		300	10
	DIMPLE (UKAEA)	O	'54	Harwell, England		—	~10
	MITR (Massachusetts Institute of Technology)	O	'58	Cambridge, Mass	ACF	1000	
	PRR—Pawling Research Reactor (NDA)	O	'58	Pawling, NY	NDA	5W	~10
	ISPRA-I (CNRN)	O	'59	Ispra, Italy	ACF	5000	8 x 10
	DIORIT (Reactor Ltd)	C	'59	Würenlingen, Switz.	Owner	1200	2 x 10
	ZED-2 (AECL)	C	'60	Chalk River, Canada	FW	0·100	
	TENNESSEE University	P	'60	Knoxville, Tenn	NDA	10	
	GEORGIA Institute Technology)	P	'61	Atlanta, Georgia	GNE	5000	
TANK	LITR—Low Intensity Test Reactor (AEC)	O	'50	Oak Ridge, Tenn	ORNL	3000	3 x 10
	WWR-2 (USSR Academy of Sciences)	O	'56	USSR		3000	4 x 10
	OWR—Omega West Reactor (AEC)	O	'56	Los Alamos, N Mex	LASL	1000	
	LPTR—Livermore Pool Type Reactor (AEC)	O	'57	Livermore, Calif	FW	1000	
	NEUTRON SOURCE Reactor (AEC)	O	'58	Upton, NY	BNL	100	
	DR-2—Danish Reactor	O	'58	Risö, Denmark	FW	5000	
	MRR—Brookhaven Medical Reactor (AEC)	O	'59	Upton, NY	Daystrom	1000	~10
	SANDIA—Engineering Reactor Facility (AEC)	P	'60	Sandia Base, N Mex	Sandia Corp	5000	
FAST	ZEPHYR	O	'54	Harwell, England		—	~10
	BR-1	O	'55	USSR		—	
	BR-2	O	'56	USSR		100	10
AQUEOUS HOMOG.	SUPO (AEC)	O	50	Los Alamos, N Mex	LASL	45	1·7 x 10
	WBNS—Water Boiler Neutron Source (AEC)	O	'52	Santa Susana, Calif	AI type AE-6	2	~10
	LIWB—Livermore Water Boiler (AEC)	O	'53	Livermore, Calif	AI type L-3	0·5	2 x 10
	APR (Armour Research Foundation)	O	'56	Chicago, Ill	AI type L-8	100	
	RRR—Raleigh Research Reactor (North Carolina State College)	O	'57	Raleigh, NC	Owner	0·5	2·5 x 10
	DR-1—Danish Reactor	O	'57	Risö, Denmark	AI type L-55	0·5	
	AI type L-54	O	'57	Tokai Mura, Japan	—	50	1·3 x 10
	AI type L-77	O	'58	Several under constr.	AI	·010	2 x 10
	HAZEL (ZETR-II) (UKAEA)	O	'58	Harwell, England		—	~10
SOLID HOMOG.	AGN 201			Some 25 under constr.	AGN	0·1-20W	10–10
	TRIGA II			Several under constr.	GD	10–100	4 x 10
	IRGA				GD	10	10
	REGA 10–30				GD	10–30	10

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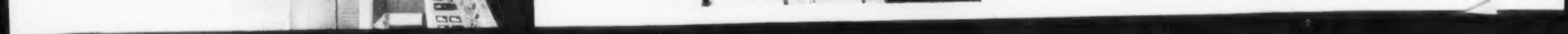
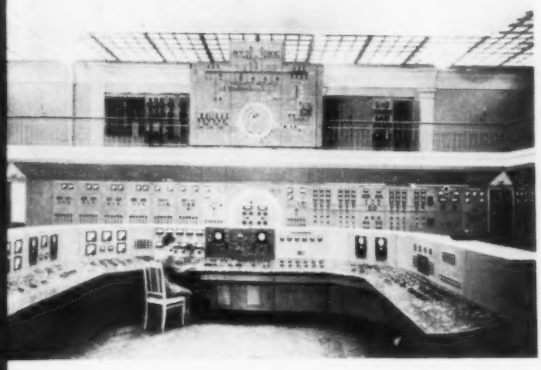
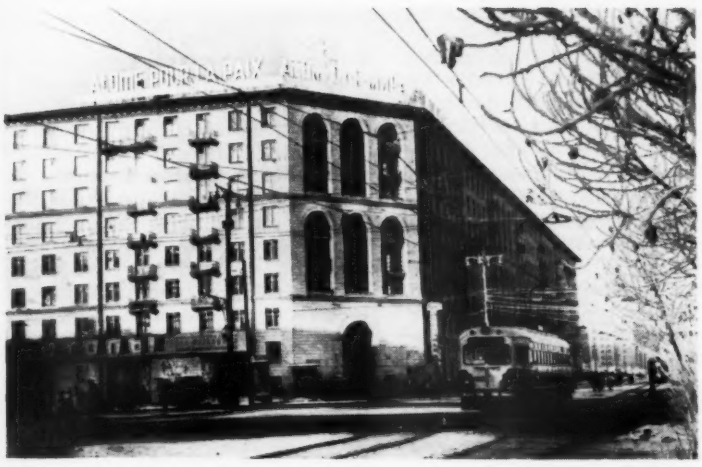
ner	1000	$6{\cdot}6 \times 10^{13}$	MTR type (20%)	H_2O	H_2O	19 sold, including Munich (O) Athens (C), Tel Aviv (C), Saluggia (O), Lisbon (C), Teheran (P), Mayaguez (C), Delft (P), Istanbul (P)
ner	5000		MTR type	H_2O	H_2O	Also at Stirling Forest, NY (C), Vienna (C)
	3000			H_2O	H_2O	Also in Venezuela (C)
ner	1000			H_2O	H_2O	Also Chulalongkorn Uuiv., Thailand (P)
ner	10			H_2O	H_2O	
ner	5000	5×10^{13}	DIDO type (93%)	H_2O	H_2O	Also Herald at AWRE, Aldermaston, and at Julich, Germany
	1000		U (20%)	H_2O	H_2O	
	100			"	"	
ner	1000			H_2O	H_2O	
ro	10			H_2O	H_2O	
ner	1000			H_2O	H_2O	
ok	10			H_2O	H_2O	
atom	—		U (1·5%)		H_2O	
N	1-100 W	$2{\cdot}5 \times 10^{8}$	UO_2/polythene	graphite	H_2O	
N	1 or 100	10^{9} or 10^{13}	UO_2/polythene	graphite/H_2O	H_2O	two cores available
	0·100	10^{6}	nat U, Al	graphite	D_2O	
	150	10^{13}	nat U, rod, Al	graphite	D_2O	
	2500	$2{\cdot}5 \times 10^{13}$	U (2%) annular	D_2O & graphite	D_2O	originally 500 kW
itutt for menergi	500	$2{\cdot}2 \times 10^{13}$	nat U, rods, Al	graphite	D_2O	
	2000	10^{13}	nat U	graphite	CO_2 at 7 atm	
L	2000	$\sim 10^{13}$	MTR type	D_2O & graphite	D_2O	
	300	10^{13}	nat U, rods	graphite	air	
	—	$\sim 10^{6}$			—	
F	1000		MTR type	D_2O & graphite		
A	5W	$\sim 10^{11}$	MTR type	graphite, Masonite	D_2O	can operate at 100W
F	5000	8×10^{13}	MTR type (20%)	graphite	D_2O	modified CP-5
ner	1200	2×10^{13}	nat U, rod, Al	graphite	D_2O	
	0·100		UD_2 rods	graphite	D_2O	testing U fuels
DA	10					
NE	5000					
NL	3000	3×10^{13}	MTR type	Be	H_2O	
	3000	4×10^{13}	U (10%), cylinders, Al	H_2O	H_2O	originally 300 KW
SL	1000		MTR type	H_2O	H_2O	
	1000					
L	100					
	5000			graphite		
strom	1000	$\sim 10^{13}$	MTR type	graphite	H_2O	
dia Corp	5000					
	—	$\sim 10^{6}$	Pu, rod, Ni blan: nat U		none	
	—		Pu, rod, s.s. blan: U		none	
	100	10^{14}	Pu, rod, s.s. blan: U		Hg	
SL	45	$1{\cdot}7 \times 10^{13}$	UO_2SO_4 (90%)	graphite	H_2O	
type AE-6	2	$\sim 10^{13}$	UO_2SO_4/H_2O (90%)	graphite	H_2O	first operated at Downey, Calif
type L-3	0·5	2×10^{13}	UO_2SO_4 (90%)	graphite	H_2O	
type L-8	100					
ner	0·5	$2{\cdot}5 \times 10^{11}$	UO_2SO_4 (90%)	graphite	H_2O	originally 10kW; new core in '57
type L-55	0·5		UO_2SO_4/H_2O (20%)	graphite	H_2O	
—	50	$1{\cdot}3 \times 10^{13}$	UO_2SO_4/H_2O (20%)	graphite	H_2O	Also at Frankfurt (O), W Berlin (O), Milan (P)
	·010	2×10^{6}	UO_2SO_4/H_2O (20%)	lead	H_2O	
	—	$\sim 10^{6}$	Uranylfluoride (90%)	graphite	D_2O	
N	0·1-20W	10^{6}–10^{10}	U (20%) in radiation stabilized polythene			
	10–100	4×10^{13}	U/ZrH alloy (20%) plates, Al	graphite	H_2O	Zirconium hydride moderator; TRIGA I below ground
	10	10^{11}	U/ZrH alloy (20%), Al	graphite		
	10–30	10^{11}	U/ZrH alloy (20%), cylinders, Al	graphite	H_2O	



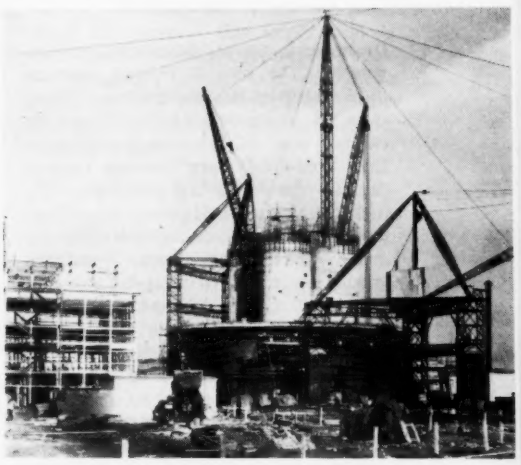
RUSSIA at the Nuclear Research Institute in Dubna the 9 GeV synchrotron is controlled from the command desk in the centre of this room



UNITED KINGDOM The 15 MW fast reactor at Dounreay, which started up in November, is now undergoing extensive tests



RUSSIA The sign 'Atom for Peace' in three languages, Russian, English and French, is lit up on the roof of 70/11 Lenin Avenue in Moscow. Here shortly, a show 'isotope' shop will be opened for the sale of radioactive isotopes and protective equipment



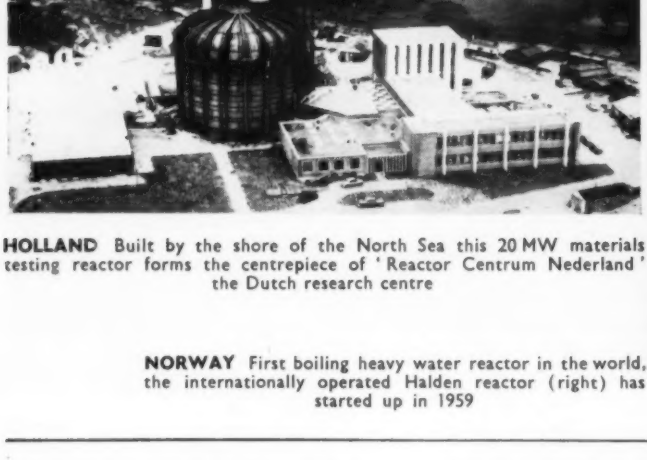
UNITED KINGDOM At Windscale construction of the 28 MW Advanced Gas-cooled reactor, prototype for the civil power stations to be built in the late 1960's, is now well under way

example, in the UK has risen sharply—black oils (fuel and diesel oil) alone from 11M tons coal equivalent in 1954 to 23M tons in 1958—and fuel efficiency, in part due to the switch to oil, has risen more than was expected. At the same time the index of industrial production remained steady between 1955 and 1958 and a world surplus of oil production has reduced the risk of an interruption of supplies for political reasons. Then, in sharp contrast to oil, coal consumption actually fell by 15M tons a year between 1954 and 1958.

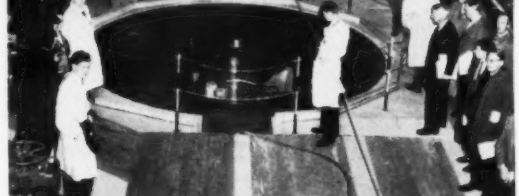
Even if industrial production continues to pick up sharply, there appears now to be no prospect of an energy shortage for some years. Indeed, the coal industry has recently been forced to recognize future growth of spare capacity; its new investment plan is designed to maintain output at 200–215M tons per annum, instead of providing a planned increase to 240M tons in 1965. Total energy requirements in the UK, which remained at about 250M tons coal equivalent during 1955-58, are now expected to rise to perhaps 280M tons in 1965, instead of the 290–300M tons forecast in 1955. The 'energy gap' which nuclear power has been called upon to fill now appears to have receded.

The latest published plant programmes of the Electricity Boards provide for 2125 MW of nuclear generating capacity in commission by the end of 1964. In order to achieve the 1966 target of 5000–6000 MW, it will be necessary to increase substantially the rate of ordering new stations during the next two years.

Whereas it was estimated in the 1955 White Paper that generating costs of the first nuclear power stations operated on base load would be about the same as coal-fired stations (about 0·6d a kWh), it now appears that their costs will be higher than those of modern coal-fired plants. A number of important factors, which in 1955 were especially favourable



HOLLAND Built by the shore of the North Sea this 20 MW materials testing reactor forms the centrepiece of 'Reactor Centrum Nederland' the Dutch research centre



NORWAY First boiling heavy water reactor in the world, the internationally operated Halden reactor (right) has started up in 1959

to nuclear power, have changed adversely. The rate of interest paid by public utilities has moved from 4% to over 5%; rising prices have affected the capital cost of nuclear plant more than coal-fired plant because nuclear capital costs per kW are proportionately higher than coal-fired plant; the plutonium credit has been considerably reduced, partly consequent upon the greater availability of cheap US uranium 235; and coal-fired plant design has advanced markedly while coal supply prospects are much easier. As a result of the changes, the estimated generating costs of stations of the latest design are 0·65–0·7d a kWh at 75% load factor.

The competitive cost requirements of the next nuclear power stations are illustrated by the cost bracket for coal-fired stations of the most modern design, ranging from 0·5d a kWh for stations on the coalfields to 0·65d a kWh for stations away from the coalfields. (Transmission costs by 275 kV line are about 0·04d a kWh per 100 miles.) Most new coal-fired plant, however, is now being built on or near the coalfields or near London. Cost requirements to be met by nuclear plant are therefore biased towards the lower end of the range, i.e. about 0·55d a kWh. It should be pointed out, however, that these estimates make no allowance for any resumption in the upward trend in the real price of coal—between 1948 and about 1957 an annual increase of over 1% took place. A rise may well start again, though it may be less steep as mechanization of the mines increases the proportion of small coal produced.

A further fall in capital costs per kW of magnox reactors can be expected from developments such as thicker plate for pressure vessels, higher coolant gas pressures, higher thermal efficiencies and general engineering design improvements. A fall of some £10–15 a kW may be achieved. Furthermore, there is a prospect of lower fuel costs resulting from the reduced uranium prices expected in the future. Together these factors may result in a fall in generating costs by as much as 15%. Moreover, during the operating life of the stations it may be possible to achieve higher burnups than the 3000 MWD/t target.

AGR will test stainless steel

The 28 MWe reactor experiment under construction at Windscale is due to come on power in 1961; it will test fuel elements canned in both beryllium and stainless steel. The higher heat ratings and thermal efficiencies possible with the system indicate that capital costs of about £80–90 a kW, inclusive of Electricity Board charges, and generating costs of about 0·5d a kWh may be expected in commercial stations. As an alternative, the AEA are also considering the possibility of a steam-cooled reactor with heavy water moderation. It is expected to have similar cost characteristics to the advanced gas-cooled reactor. The fast reactor experiment at Dounreay, which went critical in November 1959, represents a first step towards the hoped-for fast power reactors generating at 0·4d/kWh. The high temperature gas-cooled reactor also offers the prospect of low capital costs and low fuel costs because of long burnups and a high conversion ratio. At Winfrith, the zero energy reactor Zenith is being brought into operation and construction of the 10 MW reactor experiment (the Dragon joint project of the OEEC European Nuclear Energy Agency) will begin early in 1960.

The likely pattern to emerge of reactor systems in the nuclear power programme will be governed closely by the supply and demand for fissile material. Plutonium from the early stations of the nuclear power programme will not start to become available in quantity until the later 1960s. New diffusion plant and/or supplies from the US may well be required to meet U–235 demand. A balanced programme of different systems is therefore likely with some systems drawing from the fissile material pool and others contributing to it. The size of the nuclear power programme during the 1970s becomes

First Stations of the UK nuclear power programme

STATION	OUTPUT MWe	ON POWER DATES REACTOR 1	REACTOR 2	
Bradwell	300	mid 61	late 61	Under construction
Berkeley	275	mid 61	early 62	Under construction
Hunterston	300	1962	1963	Under construction
Hinkley Point	500	mid 62	late 62	Under construction
Trawsfynydd	500	1963	1964	Under construction
Dungeness	500	1964	1965	Ministerial consent given. Tenders invited

more difficult to estimate. The White Paper of 1955 suggested an upper limit of 15,000 MW installed by 1975 but subsequent forecasts have given figures up to 30,000 MW. More stringent economic requirements may well bring installed nuclear capacity back towards the original estimate.

The general delay in overseas countries' nuclear power programmes has been reflected in the lack of further export orders from Britain, following the contract for the 200 MW station at Latina, Italy, and the expected contract for a 150 MW station in Japan. Medium sized reactors suitable for export are one of the aims of the AEA reactor research programme. These may also have application for nuclear ship propulsion. In the latter case, the aim is to build an economic ship as soon as possible—the development of a suitable reactor type is likely to take some time and construction therefore cannot be expected to start in the immediate future.

RUSSIA

THERE ARE SIGNS that in the Soviet Union also the competitive cost position of nuclear electricity is not as good as it was thought to be a year ago. Then, it was confidently expected that it would prove possible to build nuclear power stations in areas remote from rivers with good hydro-electric potential and from cheap coalfields, and that these stations would generate electricity as cheaply as it could be generated from fossil fuel transported over long distances. In practice, it was recognized that such an ideal location of nuclear plants would not be possible. Because of their size they would have to be located either near transmission lines or near centres of considerable demand; inevitably, however, these centres tended to be in areas of cheap power. It was expected, however, that the cost of power in these areas would increase more rapidly than in other parts of the Soviet Union.

Last year it was hoped that power from the first 100 MWe stage of the 600 MWe natural uranium, graphite-moderated, water-cooled power station in Siberia would be producing electricity at 20–25 mills, compared with a national average cost of about 20 mills. It appears from published information, however, that this station is optimized for producing plutonium, so that its electricity may well be costed as a by-product. However, the aim of any nuclear power programme must surely be to meet the cost of the best alternative supply to the same consumers, and it is significant that what appears to have been a substantial revision of the USSR nuclear power programme has taken place in the last year.

Last year's review mentioned a power programme of 2000 — 2500 MW by the end of 1960, and doubt was expressed as to whether, on their then present showing, it was at all likely that this could be achieved. However, the Director of the Central Organization for Atomic Energy, Academician Emelyanov, had reiterated before questioners at Geneva that this remained the Soviet Union's programme, and they intended to see it fulfilled.

Building cut by half

This programme has now been put back by five years and the building programme cut by more than half. To a certain extent this cut can be attributed to pressures external to the nuclear power situation. One of the interesting revisions made when the 1959–65 seven year plan was announced early in 1959 was to change the emphasis in electricity generation from hydro-electric to fossil fuel stations. This marked part of a general turning away from investment in industries where capital charges form a high, to those where they form a low, part of total cost. Pressure on capital resources having increased, capital investment was centred on those items which would give quick returns. This, in the circumstances facing the USSR, would appear reasonable; quicker returns on capital permit an even more rapid rate of growth, or, as is more likely in this case, one less painful for the consuming public. A corresponding decision in a capitalist country would be to have a high rate of interest, appropriate to rapidly expanding economy with a high rate of return on investment.

This change of emphasis is shown in the statement made by the Soviet Minister of Power Stations Construction, I. T. Novikov, to the 21st Congress of the Communist Party of the Soviet Union: 'During the seven year plan a number of large nuclear power stations will be built. The accumulation of building and operating experience during these seven years will put us in a position to know how to optimize each reactor system used, both technically and economically; we shall thus know which system is best suited for industrial use, and what prospects nuclear power will have in the Soviet Union'. What a year ago appeared as a nuclear power programme has now become rather more akin to a reactor demonstration programme, along American lines.

It now appears that, of the Pressurized Water Reactor Programme, only one of the two 210 MWe reactors at Voronezh will be built. The second PWR station, to have been at Leningrad, has been postponed pending operating experience of the Voronezh station. It is now believed that the electricity from the Voronezh station will cost substantially more than the electricity from a conventional station.

Judging from what has been published about the design, this is likely also to be the case with the Beloyarsk Boiling Water Graphite moderated station. The system used here is a development of the Obninsk reactor, in turn a development of plutonium producing military piles. There is one reactor at present scheduled for completion in 1961, instead of four. It is graphite moderated, water-cooled and uses slightly enriched uranium. Steam is recirculated through the hottest part of the reactor and superheated. The fuel elements are robust and stainless steel canned; neutron economy is therefore likely to be poor. This, combined with the nuclear superheating (ruled out on economic grounds in the Consolidated Edison 250 MW PWR and the AEC, Rural Cooperative Power Association 26 MW BWR), would seem certain to make electricity from this system costly. Little is known about USSR costs of U–235, but they can hardly be lower than US prices. The implication is, confirmed by a recent report, that reactor designers did not take account of the price of U–235 when planning their plants; their aim was to achieve specific technical ends.

Fast reactors falling behind

There remain the Siberian plutonium-optimized stations, planned to have an electrical capacity of 600 MWe from six reactors. The first of these came on line in September 1958; nothing has been heard of them since. Presumably, however, these reactors will not be affected by economic considerations.

The plans for the Ulyanovsk Reactor Testing Station remain unchanged; four reactors are to be built there. They will be a 50 MWe Fast Reactor (BR–50), a sodium-graphite reactor and a BWR, also of 50 MWe caapcity, and a 35 MWt homogeneous heavy water/uranium oxide reactor. The BWR and homogeneous reactor were being built last year; nothing further has been heard. It is not clear whether the sodium-graphite reactor (probably a development of the Beloyarsk reactors with sodium instead of water cooling) is being built or not. The only reactor about which anything further has emerged, BR–50, indicates that detailed design work has not yet started; no date for completion is now mentioned.

This implies that the Fast Reactor Programme, upon which some emphasis was placed at the 1958 Geneva Conference, is not expected to progress as fast as was at one stage believed. BR–5, the 5 MWt fast reactor which went critical in July 1958 remains the most advanced facility in the Soviet Union. Fuelled with 50 kg plutonium oxide and

USSR Reactor Building Programme

IN DECEMBER 1958			IN DECEMBER 1959		
LOCATION	POWER (MW)	DATE	LOCATION	POWER (MW)	DATE
Obninsk	5	1965	*Obninsk*	5	1954
Voronezh	420	1960	*Voronezh*	210	1961
Leningrad	420	1960	*Leningrad*	Shelved	
Beloyarsk	400	1960	*Beloyarsk*	100	1961
Siberia	600	1960	*Siberia*	100	1958
Ulyanovsk site	150	1960	*Ulyanovsk site*	150	1963?
	1,995			565	
Possible Moscow	400		*Further Siberian reactors*	500	
	2,395			1,065	
Programme: 2000–2500 MW by end 1960			*Programme:* 2000–2500 MW by end 1965		

cooled by sodium, it is the only unmoderated plutonium power reactor in the world. This remains significant since all current fast reactor work, both in the UK and the USA, is directed towards developing the plutonium/U–238 cycle; the use of U–235 represents only an initial stage.

Though not strictly part of the USSR nuclear power programme, the commissioning in mid-September of the ice-breaker *Lenin* was probably the most important single event in 1959. This 44,000 h.p., 16,000-ton ship runs off three PWR's; any two suffice to provide full power. Not only is the *Lenin* the only surface nuclear ship afloat, but it is likely to remain the only economic nuclear ship for many years. Its range and endurance—it should be able to stay at sea for a year without refuelling—will make it possible to keep the sea-route along the north coast of Siberia open for a greater part of the year, and should improve access by water to the rapidly developing areas of Western Siberia.

The only new power reactor project relates to a 2 MW mobile PWR power station, presumably like the US APR series, for military or arctic use.

The policy of decentralizing some types of research work and providing the various Republics with their own research reactors and Institutes also continues. In addition to the swimming pool reactors building, or soon to be built, at Leningrad, Kiev, Minsk, Tbilisi in Georgia, Sverdlovsk and Tomsk, another is to be built in 1960 at Salaspils, near Riga in Latvia.

NORTH AND SOUTH AMERICA

ARGENTINE

BUILDING of conventional plant continues on a substantial scale. Lord Chandos, when he went to open a 600 MW plant built by UK Associated Electrical Industries Ltd., advised delaying the introduction of nuclear power until its real capabilities, both technical and economic, were better known.

BRAZIL

THE QUESTION of a study of the possibilities of introducing nuclear power in Brazil has been under consideration in the International Atomic Energy Agency. A power bilateral has been signed with the USA and a Triga reactor (30–100 kW) is to be built at the University of Minas Gerais, at Belo Horizonte. Several local government authorities have already invited proposals from UK and US companies for small nuclear power stations.

CANADA

SINCE IN many parts of the country power is probably cheaper than in any other industrial country, Canada has the greatest distance to travel before nuclear energy can compete economically.

Having cheap heavy water, but not finding a diffusion plant justifiable for its need, Canada is still concentrating on the natural uranium, heavy water-moderated system. As it uses a once through fuel-cycle (plutonium is not recovered from irradiated elements) consumption of uranium is naturally high compared with other systems; this has attractions to Canada as a major uranium producer.

The development of the system has been, and is planned to be, as follows:

REACTOR	MW OUTPUT	ON-POWER
Zeep	0·1 (t)	1945
NRX	30 (t)	1947
NRU	200 (t)	1957
NPD-2	20 (e)	1960/61
Candu	200 (e)	1964

Heavy water is used both as moderator and coolant in NPD-2; the latter is kept separate in a zircaloy pressure-tube assembly. The fuel will be natural uranium oxide.

Plans for Candu, the first full-scale Canadian nuclear power station, have been maturing during the last year. The station is being designed by Atomic Energy of Canada Ltd. AECL and is to be built in Ontario, probably at Kincardine on the eastern side of Lake Huron. The Ontario Hydro-Electric Commission will be sharing in this project as well as NPD-2. If this station can be built for the $M60 estimated, and if it proves metallurgically possible to burn the natural uranium fuel to 8000–10,000 MWd/t, then it is possible that electricity will be produced costing not more than the 0·51d per kWh aimed at. Perhaps the greatest economic uncertainty is in whether it will be possible to can uranium oxide in zirconium cheaply enough. Heavy water preservation also presents some tricky problems.

A variation on this system is being worked on for use in smaller generating units. This would use an organic liquid coolant in place of heavy water in the pressure tubes. Since heat transfer is more efficient, pressures can be reduced, with a saving in capital cost. The heavy water investment in the coolant circuit is also saved. The Canadian General Electric Company is going into the implications of this variant, with a view to producing a design study of a 40 MWt reactor capable of being used in the north of the country. Work will also be done on this system by the AECL; a new research centre to house the reactor experiment is to be built somewhere in Manitoba, the site to be announced early in 1960.

Finally, Canadian Westinghouse is under contract to study light water moderated systems to see whether they could be of any use in small units in remote areas.

CHILE

CHILE IS still considering the possibility of installing a 100–150 MW nuclear power station when the transmission system is better integrated in the northern and central parts of the country.

COLOMBIA

THE Colombian authorities are constructing, for training purposes, a light water-moderated, natural uranium subcritical assembly; this should be finished early in 1960.

CUBA

SINCE the change of Government nothing more has been heard of the AMF-Mitchell project for a 20·5 MWe BWR with oil superheating in the copper minding region of Pinar del Rio. The new Government has set up a Centre for the Civilian Application of Atomic Energy.

PANAMA & PERU

BOTH of these countries have now signed bilateral agreements with the USA, covering exchange of information and, in the case of Peru, provision of U–235 for power reactors. An alternative energy source may be needed for Lima after 1970.

UNITED STATES

REAPPRAISAL of the long-term energy situation in the USA, as in certain other countries, has diminished the immediate likelihood of the appearance of the so-called energy gap. For example, it has recently been argued that, given vigorous technological development, demands for conventional fuels until 1975 could be met entirely from domestic resources at constant prices.

However, the most attractive hydropower resources have already been exploited and it can reasonably be expected that the long-term upward trend in bituminous coal prices will continue.

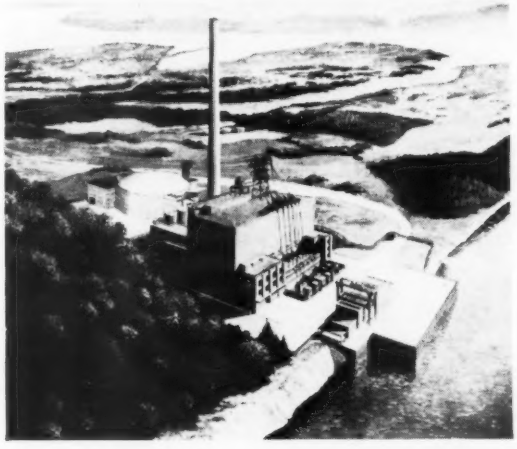
General statements about US power costs are bound to mislead, if only because generating capacity is largely in the hands of private power companies, each with access to different fuel sources. Despite the high capital cost of nuclear plant, the companies are already committed to about 1000 MWe of nuclear capacity by 1963. Forecasts of the subsequent growth of vary widely. An estimate of 50,000 MWe by 1980 (some 20% of total power installed) has received powerful support; but the uncertainties bulk very large. A shorter-term forecast is set out in Table I.

It will be seen that the short-term programme is modest and that no rapid acceleration in the installation rate is yet foreseen. This must await proof that a substantial reduction in generating costs can be achieved. During the year, the AEC has made determined efforts to create suitable conditions for this advance.

Reactor development policy

Last January (p 95), we remarked that the catalogue of reactor systems under study had become so lengthy that the research and development resources of the AEC and US industry would be stretched to their limits, despite their great size (the AEC's own appropriations for civil reactor development have risen from $M300 to $M400 in the last two years, and industrial concerns themselves wholly or partly finance large expenditures on the construction of reactor prototypes). Subsequent events have confirmed this

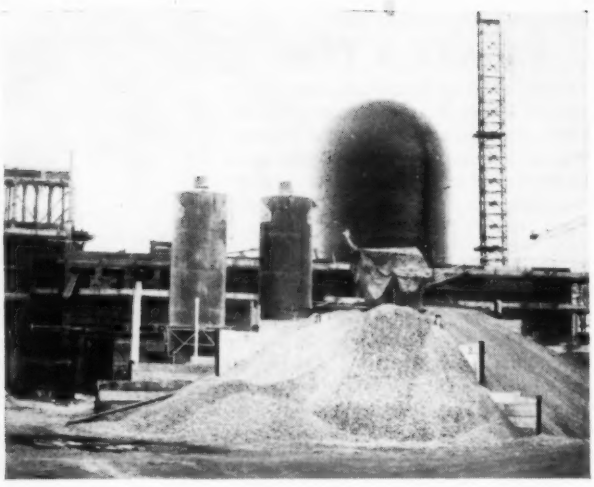
UNITED STATES The 100 MW Enrico Fermi atomic power station at Lagoona Beach, Michigan, is the world's first privately-financed full-scale breeder reactor. Built by Atomic Power Development associates it is due for completion late in 1960



UNITED STATES Consolidated Edison's thorium reactor at Indian Point, shown here as an artist's impression, will have one 275 MW reactor in the dome-shaped structure on the left

UNITED STATES The large circular building in the centre of the University of California's Radiation Laboratory houses the Bevatron. The 184 in. cyclotron is in the building on the left, half hidden by trees

GERMANY At the Nuclear Research Centre near Munich, two technicians on a platform above an atomic reactor look dwarfed by the size of the machine and the decorative ceiling with its circulating crane. This 1 MW pool-type reactor, designed and built in the US by American Machine and Foundry Company, will be used to train students



GERMANY The 12 MW FR-2 research reactor at Karlsruhe nears completion; it is scheduled to come into service in the latter half of 1960

forecast. The programme of work on fluid metal fuelled systems has been drastically reduced, and the project for the 10 MWe sodium-cooled, heavy water-moderated reactor at Chugach, Alaska, has been abandoned. The AEC are now placing much greater emphasis on systems known to be technically feasible for electricity generation.

In order to establish a basis for the execution of this new policy independent study groups have assembled data on a comparable basis for eight reactor systems which could be introduced for power station application during the next ten years. Preliminary results are summarized in Table II. (More details of recent AEC design studies will be found in Mr. Ford's review of the recent meeting of the American Nuclear Society.)

For the purposes of these studies, it has been assumed that in the later 1960's the generating costs of a conventional station in high coal cost areas will be 7·5 mills/kWh. Thus six of the systems considered above are thought to be capable of reaching this first break-even point by 1968. The ultimate objective is to break even with conventional plants in low coal cost areas (at around 6 mills/kWh) by 1975.

These comparisons, although still awaiting evaluation by the AEC, go far to explain recent changes in the reactor development policy:—

1. the AEC taking a long view of world demand for fissionable material, now place great emphasis upon neutron economy, higher fuel rating, improved thermal efficiency, and longer fuel irradiation. They may therefore wish to press forward with breeder systems (to increase plutonium and U-233 supplies) and those requiring only slight enrichment of fuel, even though the development period is lengthy and present forecast of generating costs may not be encouraging.

2. Mr. McCone has recently stated that the USA must learn how to concentrate development resources at

TABLE I Growth of US nuclear power capacity

SHORT TITLE	TYPE	MWe	START UP	CUMULATIVE TOTALS END YEAR	REMARKS
Shippingport	PWR	60	1957		later cores up to 100–175 MWe (see 1964)
Santa Susana	Sodium graphite	6	1957		—
Vallecitos	BWR	3	1957	69	—
Dresden	BWR	180	1959	249	—
Indian Point	PWR (thorium converter)	140	1960		plus 104 MWe oil-fired superheat
Enrico Fermi	Fast breeder	100	1960		later cores to 150 MWe
Elk River	BWR	22	1960	511	including 7 MWe conventional superheat
Yankee	PWR	134	1961	511	Second core
Humboldt (Pacific Gas)	BWR	60	1961	705	—
Piqua	Organic-moderated	12	1962		—
Oak Ridge	Advanced gas-cooled	25	1962	742	—
Hallam	Sodium graphite	75	1963		—
Northern States (Pathfinder)	BWR	66	1963		Including 16 MWe possible nuclear superheat
Carolina-Virginia	HW/HW	17	1963		—
Florida	GCHW	50	1963		—
Philadelphia HTRDA	HTGC	30–40	1963	~1000	May be increased to 60 MWe Or more
Shippingport	PWR	50	1964		
Other	—	~250	1964	~1300	—
—	—	~600	1965	~1900	Probably including 300 MWe BWR
—	—	~500	1966	~2400	—

vital points, and should discard attempts at the broad-based development of 13 or 14 systems.

The general pattern of nuclear power development has been noted in Table I. Interest during the past year has concentrated on the light-water and gas-graphite systems.

Light-water-moderated systems

On the estimates given in Table II, it would appear that the light water-moderated systems, which have been proven for electricity generation, are already highly developed; and therefore hold the least further development potential, even with nuclear superheating. However, there is much confidence in the future of these systems, as is shown by the following recent developments:—

a. the Dresden 180 MWe BWR has achieved criticality six months ahead of schedule;

b. the Shippingport PWR continues to operate satisfactorily;

c. the AEC are endeavouring to interest industry in a 300 MWe light-water reactor to be built with research and development assistance from the Commission;

d. the Westinghouse Electric Corporation are prepared to guarantee the capital cost, performance and fuel burnup (14,700 MWd/ton) of a 330 MWe PWR for 1965; and of a 225 MWe BWR (40% of this output being provided by conventional superheat) to be built within four years from contract date; they estimate the power costs of these reactors at 7·3 mills. Westinghouse are also advocating development of a 22 MWe prototype BWR of a pressure tube design incorporating nuclear superheating, with a view to a full-scale plant of this type to be operating in 1975.

Gas-graphite systems

Although the AEC entered the gas-graphite field late, and with some reluctance, Table II indicates that a reduction of one-third in generating costs is already envisaged (for a programme which, it is claimed, will put the US 'years ahead of the British').

Development of these systems in the USA (as compared with the UK) will be assisted by the low cost of enrichment, because the effect upon fuel costs of specifying strong fuel cans to ensure irradiation performance will not be so sharp; and because helium is readily available as coolant, which removes the problems of CO_2 graphite compatibility, at an additional cost of only 0·4 mills/kWh. If the full cost reduction is realized, the system will achieve costs comparable with those of the well-established water-moderated reactors.

The gas-graphite programme now consists of:

a. the AEC's helium-cooled 25 MWe reactor experiment at Oak Ridge, scheduled for completion in the autumn of 1962. This will use UO_2/stainless steel clad fuel;

b. the Philadelphia Electric Company's high-temperature gas-cooled reactor (with financial help from its associates and with R and D support from the AEC) to be completed a year later. The first core will use uranium/thorium carbides dispersed in graphite and canned in stainless steel, and should reach 28 MWe with a gas exit temperature of about 1000°F.

This is an ambitious schedule, although arrangements are being made for exchange of information with the UKAEA on (a), and with the European Dragon project on HTGC developments; but success on this route might bring the technical break-through which is required to establish a competitive foothold for nuclear energy in the USA.

TABLE II Comparative Costs of Reactor Development

One 300 MWe Station with a Single Turbine Operating at 80% Load Factor
U-235 at Current Published Prices Plutonium Credits at $12/gram

	PWR	BWR	BWR + superheat	Organic-cooled and moderated	Sodium graphite	Gas-cooled graphite (natural uranium costs in brackets)	Heavy water natural uranium system	Fast reactor system	Aqueous homogeneous thermal breeder
I *Generating costs based on present technology, mills/kWh:*									
Capital costs	5·1	5·2		4·4	6·1	6	7·1	5·1	} Technical
Fuel cycle costs	3·4	3·5		5·7	4·1	3·2	4·2	7·1	} feasibility
Operation, maintenance and insurance	0·8	0·9		1·3	1	1·2	1·2	1·1	} not yet established
TOTAL	9·3	9·6		11·4	11·2	10·4 (11·9)	12·5	13·3	
II *Generating costs taking account of foreseeable advances in technology, mills/kWh:*									
Capital costs	4·4	4·3	3·9	3·7	4·9	4·1	6·5	4·4	6·4
Fuel cycle costs	2·6	2·3	2	2·1	1·9	2·8	1·3	2	2·1
Operation, maintenance and insurance	0·8	0·9	0·9	1·3	1	0·8	1·2	1·1	2·8
TOTAL	7·8	7·5	6·8	7·1	7·8	7·7	9	7·5	11·3
(and date of construction start)	(1960)	(1964/5)	(1965)	(1965)	(1965/6)	(1966)	(1967/8)	(1968/9)	(1970/1)
III *Cost of additional R and D effort needed to advance from* I *to* II ($M.)	20	20	24	40	82	100 (exc. HTGC)	80	160	75
Cost of prototypes		25	20	30	50	30	175	55	100

Conclusion

It is to be expected that the Ten-year Programme to be drawn up by the AEC in 1960 will produce a further concentration of effort upon a few feasible reactor systems. The commission's attempts to systemise activities in the related fields of fuel processing and economy in the use of fissile materials, and to limit R and D assistance to projects forming part of a coherent framework, are laying the foundations for such a programme.

VENEZUELA

A POWER bilateral has been signed with the USA, authorizing the delivery of up to 800 kg of 20% U–235, and 6 kg of 90% U–235 for power and research reactor use. This will serve to cover, amongst other things, the supply of fissile material to a 3–5 MW swimming pool to be built by General Dynamics.

ASIA AND AUSTRALASIA

AUSTRALIA

NO DECISION to build a power reactor has yet been taken. Long term reactor research is still being concentrated on the high temperature gas-cooled system.

The 10 MW materials testing reactor Hifar in the research establishment at Lucas Heights is being extensively used and the irradiation facilities have been offered to UK companies. During the year workers at Lucas Heights developed their own system of nucleonic instrumentation for use in the research programme.

CHINA

THERE IS little new to report ; the fact that the Chinese Minister of War has reiterated China's determination and ability to manufacture nuclear weapons implies a considerable basis of nuclear knowledge, and access to a substantial nuclear energy industry.

The 6·5–10 MW heavy water-moderated research and materials testing reactor supplied by the USSR under a 1955 agreement has now been in operation for fifteen months. Canada is to supply six cancer therapy machines using cobalt-60 sources.

INDIA

THE 1961–66 five year plan provides for a 250 MWe Calder-type nuclear power station at a cost of Rs.45 crores (£M34 or just under £138 per kW). It is planned that construction should start in 1961 and the station come on line in 1964. Preliminary talks have already been held with the consortia. There is a possibility that this programme might be substantially increased to 1000 MW by the end of 1965. The total investment in such a programme would be just under £200 million. Ultimately, it is aimed to use the thorium/U–233 cycle in Indian nuclear power stations, thus making use of plentiful domestic supplies of thorium.

The first station is to be built near Bombay ; its precise location has not been decided, but it would be an advantage if the station were also in a position to supply the densely populated area round Ahmedabad, to the north.

Preliminary steps have already been taken to ensure that India will be able to construct herself all the ancillary plant necessary to sustain the substantial programme envisaged. The first all-Indian billet of nuclear grade natural uranium was produced in February 1959 ; a fuel element fabrication plant has been set up and work has been done to show that it is possible to make graphite domestically. A 14 ton per annum heavy water plant is already being built.

India has decided to build her own chemical separation plant—on a modest scale at first—which will deal with irradiated fuel rejected from research reactors ; this probably means a capacity of some 20 tons per annum.

Other aspects of the programme also continue to press forward. The joint Canada-India 40 MWt reactor at Trombay, an improved version of NRX, should be critical next March. This will mean that many, if not all, of the fuel elements will have to be fabricated abroad. The Apsara swimming pool reactor, built with UKAEA help and using British U–235, has now been operating at Trombay for 2¼ years. A further research reactor, Zerlina, is expected to go critical shortly.

The first reactor system to be investigated by the Indians themselves with a view to adoption for power production is expected to use natural uranium fuel, a heavy water moderator, and an organic liquid coolant. Longer term plans favour the investigation of organic liquid moderated systems using thorium.

INDONESIA

THE Indonesian government has set up a Council of Atomic Energy to advise on political matters, and an Institute of Atomic Energy to undertake research, supervise prospecting and encourage the use of radioisotopes in medicine, agriculture and industry.

JAPAN

SINCE IT would not be within Japanese capabilities to construct and run a diffusion plant capable of satisfying the needs of a substantial power programme, attention has been directed primarily towards the natural uranium, Calder-type reactor. 1959 was mainly of interest in that it witnessed the negotiations leading to the issue of a letter of intent for the first imported nuclear power station.

The responsible authority, a specially formed group of electricity producing companies—the Japanese Atomic Power Company (JAPC)—had in 1958 invited tenders for a 150 MWe Calder-type station. Bids were received late in 1958, and were first scrutinized from a technical point of view. Separate envelopes, containing the costs of the bids were not opened until later, January 16, 1959. The Japanese considered that the three bids received (from the UK General Electric, English Electric, and AEI–John Thompson consortia) were so close technically that there was little to choose between them. It appears that there was also little difference in the prices asked ; they were all in the neighbourhood of £M19. Since the prices all appeared to be substantially above that agreed for a station of the same size to be built for Italian AGIP-Nucleare, the Japanese asked the consortia to reconsider them. However, most of the difference in price was due to higher transport costs for the imported components, and greater civil engineering work to protect the reactor against earthquakes, so that it proved possible only to make a fairly modest reduction. The General Electric-Simon Carves Consortium was chosen and the price agreed on is reported to be about £M18, i.e. £120 per kW. It seems likely that Japanese firms will now be responsible for about one half of the work on the reactor and ancillaries, and presumably for all the conventional part of the station (including civil engineering work). It thus appears that one of the objectives of the initial stages of the nuclear power programme will be reached ; drawings on overseas earnings will be kept below the planned figure of 40% of the total cost of the station.

During the negotiations it was announced that an agreement had been made with the General Electric Company of the UK arranging cooperation on nuclear power generation. The UKAEA has, relatedly, also concluded a consultancy agreement with the JAPC which will cover, amongst other things, advice on operation.

The Japanese government has given its formal approval to the building of this station shortly. Because of safety fears, including local objections to the siting of the station at Tokai Mura, the government decided to submit the safety problems of the reactor to a special Reactor Safety Committee. This made a favourable report in November.

The Boiling Water Reactor System also interests the Japanese, possibly for ship propulsion. It is, therefore, planned to install a 12·5 MWe uranium oxide-fuelled BWR, also at Tokai Mura. This reactor should be in operation in 1962, though there have been some difficulties in negotiating satisfactory accident liability provisions. It will be built by the US General Electric company and should cost about £M3.

The most important development in Japan's own research programme has been in connexion with JRR–3. This is a research and materials testing reactor, heavy water-moderated and natural

uranium-fuelled, which is due to be completed in 1961. The Japanese have acquired the right to three tons of uranium metal from the International Atomic Energy Agency, at a price of $16 per lb, subject to the Agency's peaceful-uses safeguards. The remaining 3·6 tons of uranium will be Japanese mined and refined, though canned abroad—possibly in Canada.

A bilateral agreement has been signed with Canada, after protracted negotiations, to cover information on reactors and the supply of heavy water and uranium. A number of training reactors, mostly low powered Trigas (up to 100 kW) have been bought ; these will be going to Rikkyo, Kinki and St. Paul's Universities, and to the Musashi Engineering College at Kawashi.

Finally, looking further ahead, the Japanese Atomic Energy Research Institute is working on a high temperature gas cooled thermal breeder reactor. The fuel would be uranium oxide and thorium oxide in graphite. This reactor bears a close family resemblance to the OEEC project Dragon, at Winfrith.

Thus, Japan is, by hard and successful bargaining, using its position as an economic buyer of nuclear power plant and equipment to lessen its technical lag in development. What remains to be seen is not whether Japan will catch up on past developments—that is not in doubt—but how extensive her contributions to nuclear knowledge will be, and how soon they will be made.

NORTH KOREA

RUSSIA HAS undertaken to help to establish a research centre, to include a reactor, physics and isotope laboratories and a betatron.

SOUTH KOREA

THE USAEC will contribute $350,000 towards setting up a research centre and installing a Triga Mark II 100 kW reactor at the Seoul Atomic Energy Research Institute.

NEW ZEALAND

LITTLE has happened in the atomic energy field during the last year. Most of the power generation effort is still being devoted to increasing hydro-electric supplies. Nevertheless a continuing interest is maintained in overseas development of nuclear power and a small but growing research effort is undertaken. The purchase of a research reactor from overseas is under consideration. When nuclear power becomes an economic possibility, the first station is likely to serve the chief national load centre at Auckland. A 3 MV particle accelerator, costing some £80,000, has been ordered from the US.

PHILIPPINES

THE US General Electric company will be installing a 1–3 MW swimming pool reactor, which should be completed in late 1960 ; the cost of the US components will be about $500,000.

THAILAND

A 1 MW swimming pool research reactor is to be built at Chulalongkorn University, Bangkok. The US is contributing $350,000 to its cost. There are reports that the possibility is being considered of importing a 20–40 MW power reactor for the North East region of the country.

VIET-NAM

A 1000 kW Triga Mark II is to be installed in a nuclear research centre at Delat ; the US will pay $350,000 towards the project.

AFRICA AND THE MIDDLE EAST

IRAQ

THE NUCLEAR energy research centre associated with the Bagdad Pact countries has been moved to Teheran and no longer concerns Iraq. In its place Iraq has signed an agreement with the USSR providing for technical assistance in building a reactor and an isotope laboratory, and for training scientists in the Soviet Union.

ISRAEL

A GROWING effort is now being devoted to nuclear research. A 1 MW pool reactor under construction by AMF Atomics (scheduled operation late 1959) for the Weizmann Institute.

SOUTH AFRICA

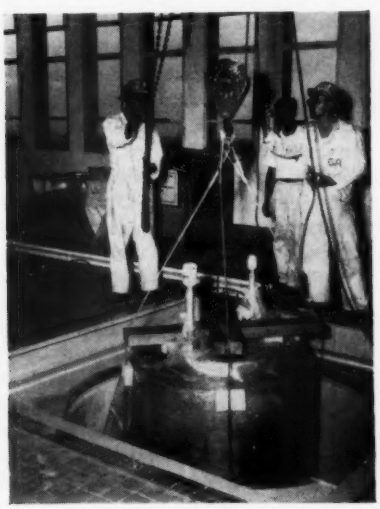
THE PURCHASE of a 5 MW pool-type reactor from overseas has been approved in principle.

TURKEY

IN TURKEY work continues on a 1 MWt research reactor and associated research centre.

CANADA One of the first atomic research centres in the world, the Chalk River establishment has grown so large that an additional centre is now to be set up at Manitoba

BELGIAN CONGO This Triga, first research reactor in Africa, is now in operation at the Lovanium Catholic University, about 12 miles from Léopoldville



Six experts appraise developments during 1959 in the fields of reactor engineering, reactor physics, fuels and materials, nucleonic instrumentation, process chemistry, and applied irradiation

WORLD REVIEW OF PROGRESS IN TECHNOLOGY

1. Reactor engineering

by R. F. W. GUARD, B.Sc.(Eng.), A.M.I.E.E.
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THE EFFORTS of all designers have been directed towards reducing capital costs. Higher interest rates and reduced load factors have made capital charges the critical factor. Minimum guaranteed first cost for a maximum guaranteed output is now the principal objective, largely because fuel costs remain hypothetical and fuel guarantees are decided more by politics than by statistical evidence.

The gas cooled reactor

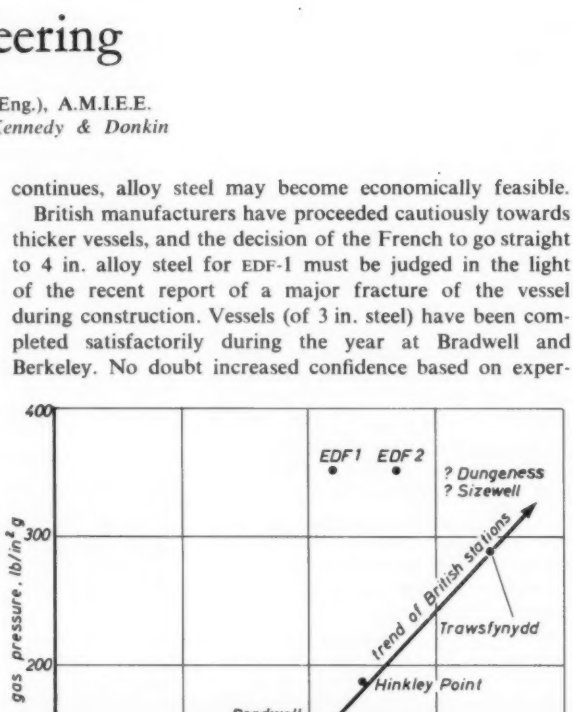
In spite of fierce controversy about the future of the present type of GCR (magnesium canning), engineering developments continue more rapidly with this reactor type than any other, thanks to the incentive of the CEGB programme. Design outlines of the Trawsfynydd (*1*) and Latina (*2*) stations have been published, and a little information on Tokai-Mura (*3*). From these a number of interesting trends may be inferred.

System design Gas pressures continue to rise, in spite of occasional statements that the practical or economic limit has been reached. Clearly, designers find that the improvement in performance justifies the increased difficulty, and it is apparently more efficient to increase blowing power rather than the reverse. A greater volume of core has been fitted into a given vessel volume, and also a greater weight of fuel, possibly with some small reduction in excess reactivity.

The number of primary loops is settling down at four or six. The first reactors had up to eight, while EDF-1 has one. It is desirable to be able to lose a circuit without having to shut down. Gas outlet temperatures are unchanged, but inlet temperatures are tending to rise.

Pressure vessels The principal obstacle to increased gas pressure is the design of the main vessel. The new designs include means to reduce the top dome temperature, and both Latina and Trawsfynydd cool the outside of the vessel and insulate the inside surface above the core. Plate thickness at Trawsfynydd (3½ in.) is less than at Latina, although the pressure is higher; obviously the improved core/vessel volume ratio has paid handsomely by permitting a smaller vessel. If the trend towards reduced sizes continues, alloy steel may become economically feasible.

British manufacturers have proceeded cautiously towards thicker vessels, and the decision of the French to go straight to 4 in. alloy steel for EDF-1 must be judged in the light of the recent report of a major fracture of the vessel during construction. Vessels (of 3 in. steel) have been completed satisfactorily during the year at Bradwell and Berkeley. No doubt increased confidence based on experience will permit the use of 4 in. plate and increased pressures in future designs (Figure 1). New methods of radiography, possibly using particle accelerators, will probably be developed. One manufacturer has published a paper (*4*) on the band reinforcement of large cylindrical vessels, which seems perfectly feasible.



Increased gas pressure is a feature of the development of gas-cooled reactors (Fig. 1)

Gas ducting, bellows and valves The higher pressures make increasing demands on these components, and a recent paper (*5*) analyses the problems. The expensive and vulnerable bellows might be eliminated if the ducting could be allowed to flex, but none of the recent designs incorporate this improvement. Trawsfynydd shows spherical corner-pieces at right-angle bends instead of the usual

mitre. Butterfly valves are now standard, but it is suggested that perfect sealing under both hot and cold conditions may be impossible to achieve.

Gas circulators The expensive and less reliable variable speed drives for circulators, bequeathed by Calder Hall to the first four British stations, have been ousted at Trawsfynydd by squirrel-cage motors and valve/bypass control of gas flow. The case for variable speed drives for base-load stations had never been clear. Reactors built abroad on transmission networks with different characteristics may require v.s. drives, and the direct steam-turbine drive proposed for Tokai-Mura is likely to be less expensive than the Latina variable-frequency drive, which copies Bradwell.

Core design It has been a difficult year for core designers. In 1958, following the Windscale accident, the UKAEA decided that the storage of Wigner energy in the cores of the industrial reactors would have to be reduced by raising the minimum graphite temperature. One way to achieve this without increasing the gas inlet temperature is to insulate the coolant channels with sleeves, and the Trawsfynydd core includes this feature. It is, therefore, very interesting to note that Latina is not to be sleeved. This may mean that Latina will require an irradiation anneal after some years, and presumably the Italians are prepared to carry out this operation while the CEGB are not.

Recently it has been found that under certain conditions graphite will shrink rather than grow. Much thought had been put into core design from Calder onwards to allow for growth, but shrinkage raises new problems of core stability and alignment. The solutions adopted have not been published, but an independent Japanese study of the stability of a core under earthquake conditions, even allowing for shrinkage, concluded that the re-design was satisfactory.

Fuel elements The Trawsfynydd elements present no surprises, but it is stated that hollow elements were considered and rejected (*1*). This seems to be another example of CEGB conservatism, as the Japanese are said to have accepted hollow elements, which obviously can produce much more power per ton. The French elements are also hollow, but the uranium is stabilized with molybdenum, with some loss of reactivity. Obviously hollow elements are far behind in practical irradiation experience, and one problem with them is to forecast what goes on inside the hole.

Fuel handling The trend seems to be towards a single giant machine which carries out all operations at one attachment to a stand-pipe. GEC have gone to top-charging for Tokai-Mura. The discussion on a recent paper (*6*) suggested that most people prefer remote control to direct operator action. A man sitting on the machine may have a better feel of things but he is in a very vulnerable position if anything goes wrong.

Steam cycles The dual pressure cycle remains, but Trawsfynydd has higher steam pressures and a reduction in superheat. The advantage is smaller steam drums and pipes, but the wetness at the turbine exhaust is now severe by conventional standards. American reactor steam cycles have always penetrated well into the wet region, and designers have relied upon moisture extraction devices which are not yet familiar here.

Safety The latest reactors have an emergency shut-down device, designed to insert absorber (e.g. boron-steel balls) into the core under accident conditions. Trawsfynydd boilers are shielded, with the drums outside the shield walls, permitting maintenance to be carried out without need to enter radiation areas.

Construction In spite of the excellent civil construction record at Berkeley without the use of a Goliath crane, it is proposed to use one at Trawsfynydd. So this controversy continues unresolved.

Water-cooled reactors

While the pressurized water reactor remains well in the lead for ship propulsion, the boiling water reactor is having greater success for power generation applications. Not many design developments have been reported during the year, but it is possible to compare the Garigliano plant design (*7*) with Dresden.

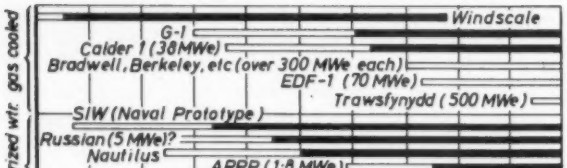
It is easier to measure instability in a BWR than to predict its onset, and manufacturers tend to guarantee a lower thermal output than they believe may be possible. Stability requires that the reactivity absorbed by steam voids in the boiling fluid shall not be too great, and the void fraction can be reduced by pressurizing and by sub-cooling the water entering the core below the saturation temperature. Dresden has four primary loops with heat exchangers, which provide the sub-cooling and raise secondary steam. In the Garigliano design the proportion of secondary steam is much reduced and there are only two loops. Capital cost is reduced and efficiency is increased because the designers have more confidence about the stability problem.

In PWRs on the other hand, the drive is towards increased power density in the core by permitting local boiling. Hence as far as core and vessel design is concerned, the two types are becoming indistinguishable. The big difference is the direct cycle used for the BWR, and it is extremely interesting to note that active steam will be passed directly to a full-scale turbine at Dresden very shortly.

A contract for building a large PWR station in Italy has been signed, but few details differing from the Yankee plant have been published. 50 MWe BWRs are building at Humboldt Bay and in Michigan. It is significant to note that the Germans chose a closed-cycle BWR for Kahl which will not have a radioactive turbine. A period of intense competition in the field of small power reactors has begun between the two major American companies who promote the BWR and PWR respectively; both have announced ambitious development programmes. One of these firms insists on zirconium as a canning material, while the other prefers stainless steel—further evidence of meagre burnup experience.

America's nuclear navy reactors remain secret, but a recent review (*8*) suggests that their designs are very different from a commercially practicable PWR. Where money and neutron economy are no object, cores use fully-enriched uranium, heavily doped with burnable poison to increase core life. Oxide is not used because of its poor shock resistance.

In reactors where no fuel charging on load is possible, very poor power distributions develop with irradiation and a compromise has to be made between a poor average burnup and frequent shut-downs for fuel changing. In the



Development history of the three main power reactor types

larger sizes of reactor, handling of the head closure is extremely difficult.

Another design problem to be overcome with liquid-cooled reactors is the identification of defective fuel elements. It was interesting to see recently proposals for this from a British manufacturer (*9*).

Proposed tightening of radiation limits in the USA recently caused a considerable political storm. The trend towards increased safety may be seen in the licence granted to the Piqua plant, which was conditional upon adding containment. The big PWR at Indian Point (a curious plant incorporating a thorium blanket and an oil-fired superheater) is to have a containment vessel of 1½ in. steel, clad in concrete with an average thickness of 5½ feet.

Other reactor systems

Although the Advanced Gas-Cooled Reactor may be regarded partly as an engineering development of the GCR, it is really a different system in most respects. Most interesting are the means of cooling the vessel and ducting, effectively separating high temperature parts from stressed parts.

Heavy water moderated reactors seem to be dogged by controversy. Lewis presented a paper (*10*) in April on Canadian experience but severe criticism of his policies have been reported. The Swedish programme has been severely cut. In spite of forecasts made a year ago of the development of a heavy-water moderated system in this country, no prototype has been started, although we are participating in the Halden experiment. In a similar position is the Organic-Moderated Reactor, still not accepted anywhere for major construction except for the 12 MWe plant at Piqua.

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2. Reactor physics

by D. A. NEWMARCH, B.Sc.
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THE USE of reactor calculation techniques requiring electronic computers is increasing. Although an uncritical reliance on such methods has been justly condemned, the effort to improve reactor designs involves not merely finesse in evaluating common design parameters but also an appraisal of the complicated spatio-temporal changes that reactors undergo during operation, especially under conditions of high burnup. Without recourse to electronic computers such an appraisal would be extremely tedious and probably impracticable. It may also be hoped that computer methods will eventually dispense with the need for the vast experimental programmes required to provide empirical parameters for approximate theories.

Reactor survey programmes

The various aspects of reactor design must not be considered independently. Indeed it is sometimes found that by tracing the effects of some small design modification through the various equations of heat transfer, lattice physics etc., a feedback occurs such that the modification aggravates the situation which it was intended to alleviate. This consideration has led to the increasing use of reactor survey programmes. These programmes iteratively solve the equations governing the various design aspects and print a consistent set of design parameters. A survey programme uses such data as net power output, fuel element design parameters and reactor size limitations, and from these computes engineering performance (heat rating, pumping power, thermal efficiency etc.), cost per unit power, enrichment and lattice physics parameters.

In order that the machine time should not be excessive, only simple forms of equation can be used. However, although this means that no final conclusions can be made from the results of such computations, these programmes define more precisely the field of interest. The approximate design thus having been determined, more sophisticated methods can be brought into play.

Short-term instabilities in graphite power reactors

During the operation of reactors at steady power, changes in flux and reactivity occur. The short-term instability effects are those occurring on time scales ranging from a few milliseconds to a few hours. They are due to two principle sources:

1. The presence of delayed fission product poisons, notably Xe-135. A local increase in flux, by means of increased burnup, causes an inital decrease in this poison concentration thus further tending to increase the flux level.

2. Possible positive temperature coefficients. These are especially likely to arise as the plutonium content of the reactor increases.

Uniform control of graphite power reactors is thus inadequate since the instabilities would lead to local overheating even if the total power output were kept constant.

It is necessary therefore to have, in addition to the main control system, a set of fine sector control rods which respond to local flux changes.

A certain amount of work has been done by analytical methods (*1*); in addition the STAB programme for the IBM 704 and 709 has been written at AERE. This is a three dimensional programme which solves iteratively the coupled neutron diffusion, heat transfer, xenon poison, and control equations. The control equations determine the nature of the response of the fine sector control rods to flux changes. The programme first computes and prints the steady state values of the flux, xenon distribution etc. Further data, by altering some of the parameters, simulates the effect of perturbations. The programme then computes and prints, for a succession of time steps, such quantities as the flux distribution, xenon distribution and the degree of insertion of the control rods.

Flux spectra and effective cross-sections

Several papers on topics relevant to the accurate computation of flux spectra were presented at the second Geneva Conference. Since then, considerable effort has been devoted towards applying and improving these methods.

Limitations of simple methods of computing spectra

Simple methods, based on the model of a Maxwellian component joined to a $1/E$ tail, generally do not introduce serious errors when applied to the initial state of uranium-fuelled graphite or heavy-water moderated reactors. This is because:

1. The ratios of fuel to moderator and thermal absorption cross-section to epithermal removal cross-section are low; also the total cross-sections of the moderators vary little up to MeV energies. Under these conditions the model provides a fair representation of the spectrum.

2. The absorption cross-section of the reactor materials usually all have an approximately $1/V$ dependence at thermal energies. This results in the thermal utilization factor being insensitive to the spectrum shape. Small errors in the thermal diffusion length are not usually of great importance in such assemblies.

These methods have a seductive simplicity, and the speed with which they can be performed leads them to be written into computer programmes in which the lattice physics calculations appear as subroutines.

Special case of water-moderated assemblies

These simple methods are unreliable when applied to light-water moderated assemblies: the high thermal absorption distorts the lower end of the spectrum from a Maxwellian shape. Above 0·01 MeV the hydrogen cross-section decreases rapidly with increasing neutron energy, thus causing a high energy flux peak, while the massive amounts of U-238, canning and alloying materials affect the fast spectrum in a complicated manner. Also, because of the severe control problems usually associated with water-moderated assemblies, accurate evaluations of the thermal diffusion lengths are required.

A scheme for computations on water moderated assemblies, developed by Westinghouse Electric, was presented at Geneva (paper 1843). In particular the thermal spectra are computed by the Wigner Wilkins method using the SOFOCATE code, while the fast spectra are computed by the MUFT fifty-four group code. It was claimed that, when properly used, the scheme can be expected to give reactivities correct to within 1 or 2%. An AERE analysis of highly enriched assemblies, which was based on this scheme, supports the claim. Also experiments on relative reaction rates, using a variety of detectors, correlate well with SOFOCATE computed values.

The use of the MUFT/SOFOCATE combination for low enrichment assemblies is complicated by the large amount of U-238 present and the large fine structure effects. These make it necessary to introduce self-shielding factors. Geneva paper 1841 listed an excellent correlation between experimental and theoretical results; it was stated that the self-shielding factors were obtained by the Monte Carlo method. More satisfactory methods of obtaining these factors are now being sought.

General methods of spectrum calculation

The need to predict reactor behaviour under conditions of plutonium build-up has stimulated efforts to derive satisfactory methods of computing spectra which can also be applied to graphite-moderated assemblies. The plutonium cross-section, peaking at 0·3 eV, may result in positive temperature coefficients, the magnitude of which are spectrum sensitive. Three main approaches are being made to this problem:

1. *The Wilkins equation* is used to compute the thermal spectra. The spatial dependence can be introduced by means of self-shielding factors, but a better approach, due to Takahashi, is to use coupled sets of equations with terms which allow for scattering from one zone to another (*2*).

2. *Multigroup diffusion theory methods.* A derivation of transfer cross-sections for a crystalline moderator was given at Geneva (paper 18). These cross-sections are thought to be valid if the energy change is not too small. They have since been written into an AERE multigroup diffusion theory programme which has produced results for graphite moderated assemblies differing little from those obtained with the ideal gas model. Transfer cross-sections for small energy changes can be measured; these could be used together with the theoretical cross-sections for large energy changes to provide an improved technique for computing spectra.

3. *Transport theory methods.* The principle method is the Carlson *Sn* technique; this should be more reliable than diffusion theory methods when applied to assemblies with pronounced fine structure. Unfortunately this method is expensive in computer time.

Streaming effects

It has long been known that ratios of the axial to radial components of the migration area, when computed by the Behren's method, give values incompatible with experiment. It was not known, however, which of the two components was in error. A Monte Carlo study of the problem, reported at Geneva (paper 310), then showed that it was the radial component in error. Work has since been in progress to find an analytical method of obtaining the radial component (*3*).

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3. Nucleonic instrumentation

by DENIS TAYLOR, M.Sc., Ph.D., M.I.E.E.
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THE DEVELOPMENT of nuclear instrumentation has followed the same general pattern as last year (*1*). There have been few major advances in measurement technique but trends indicated then have been maintained. Thus transistors are being employed to an increasing extent, particularly in portable radiation monitors, where the decrease of size and weight of the instrument is a considerable advantage. In the larger instruments, e.g. those used in reactor control, the most significant achievement in the use of transistors is the reduction in the amount of heat generated by the equipment. To quote an example, one instrument for reactor control using transistor circuits dissipates only 10 watts as compared with 500 watts in the case of the equivalent unit using thermionic valves. There is also a considerable space saving, and in the case of reactor instruments this can amount to as much as 80%.

Radiation detectors have not changed markedly in the past year, but successful demonstrations have been made of in-pile detectors for reactor control purposes. These are ionization chambers with coatings of U-235 on the electrodes. There is no doubt that in-pile detectors will be used to an increasing extent in the next few years.

The introduction of the photoconductive crystal as a radiation detector is taking a long time, but crystals are becoming available with a short response time (of the order of a few seconds) and with a sensitivity of several (5–20) microamp per r/h at 100 volts. They offer the possibility of producing simple dose-rate monitors and contamination monitors, probably at a fraction of the cost of that possible with either a geiger counter or an ionization chamber.

Photoconductive crystals are also finding application in data-handling systems. Thus in handling the outputs from a large number of thermocouples a high speed switch is needed which is not limited in operation by contact potential troubles. Photoconductive crystals appear to be suitable for this purpose. The best crystals produced so far have a dark resistance of 10^8 ohms and a bright light resistance of 10^2 ohms, giving a change of resistance by a factor of 10^6.

Recently there has been an interesting development in connexion with the use of pulse counters for reactor control purposes (*2*).

Particle identification method

Another new technique (*3*) is pulse shape discrimination using scintillation counters to determine the nature of the particle causing a scintillation even as pulse amplitude discrimination is used to determine the energy of the particle. Several different techniques have been developed. Some use small and large time constants to produce pulses corresponding to peak amplitude and total current from the photomultiplier. Others use space-charge limitation in the photomultiplier to distinguish a large peak-amplitude scintillation from a small peak-amplitude scintillation response. It would appear (*4*) that space charge saturation provides a simple method of detecting fast neutrons of energies between at least 0·5–10 MeV. In this range, detection efficiencies are of the order of 10–20% per cm of phosphor, whilst gamma rays, which have absorption coefficients about half that of neutrons, can be largely rejected. So far pulse shape discrimination has been used in specialized laboratory experiments and research. In the future, however, it may find application in health physics instruments, e.g. in neutron monitors.

Two new transistor applications

Scaling equipment has not changed appreciably in the past year. Perhaps the most interesting development is that using transistors. Several years ago Chaplin described a binary scaler using transistors in which an inductance or delay line provides the short time memory, the resolution of which is limited almost entirely by the switching speed of the transistors. With the faster transistors now available very much faster scalers have become possible. Thus with the new Mesa transistors it should be possible to develop a 100 Mc/s scaler, which will have obvious applications in experimental work with the new particle accelerators.

Transistors are also being employed with success in fast coincidence circuits for nuclear physics measurements where it is often necessary to detect light signals in a scintillator which coincide with signals from other scintillators. The usual technique involves forming the output from the photomultipliers into narrow pulses of constant amplitude and mixing them so that an output is obtained only when pulses overlap. In a new circuit proposed by Chaplin and Candy (*6*) diodes and transformers are used to shape the pulses and a transistor amplifier to provide the output signal. The circuit, which will respond to input pulses of one volt or greater, has a resolving time of 3 millimicroseconds.

A new development is the beryllium survey meter in which detection of beryllium in the field is made possible by incorporating in the instrument a gamma source and relying on a (γ,n) reaction for the detection and location of the ores. With the apparatus developed at AERE an antimony gamma source is employed and a BF_3 proportional counter used as the neutron detector, followed by a pulse amplifier, discriminator and count register, all circuits being transistorized. The sensitivity is adequate to measure a beryl content which is too low to make extraction economically practicable—for example 50 ppm will double the background counting rate.

Recently there has been considerable interest in low energy gamma-ray monitoring and assay of fissionable material. In the case of Pu-239 a low energy gamma ray (17 keV) is emitted in some of the disintegrations in addition to the alpha particle, and this gamma emission has proved a very satisfactory means of detecting extremely minute amounts of plutonium (*5*). The same method has been used with success in the case of U-235 which emits gamma radiation of 184 keV in addition to alpha particles.

Pulse amplitude analysers continue to be required on an increasing scale, but with the increasing number in use the handling of the information obtained is creating in turn a new problem. In some cases print-out facilities are provided and the information is stored on punched cards for subsequent analysis using a digital computer. In some cases, on the other hand, it is convenient to store the information on tape, and this method is becoming very popular.

Developed by A.E.R.E., this transistorized beryllium survey meter for detection and location of ores incorporates an antimony gamma source and a BF_3 prportional counter as neutron detector

Determining weak radioactivity

A very recent development in health physics is the problem of ascertaining whether the activity of a weak radioactive sample is above or below a pre-determined level. Cooke-Yarborough and Barnes have studied this problem and attempted to determine the most efficient method of making such measurements. This means determining the shortest time of measurement with an acceptable low probability of error. In the past in hand monitors, for example, two circuits have been used, a counting circuit and a timing circuit. The counting circuit is fed with charge pulses from the counter and these are used to charge a capacitor which, when it rises to a set voltage, operates a trigger circuit operating the 'high' alarm. Meantime constant current is fed to a capacitor in the second (timing) circuit which operates a 'low' alarm if it reaches the pre-set voltage first. At the end of this period both capacitors are discharged and the sequence can be started again.

In the new circuit proposed by Cooke-Yarborough and Barnes, charge is fed to a capacitor from the discharges of the counter as in the previous system, but a constant current (corresponding to that current which would be fed to the capacitor with a mpl on the hands) is bled from the capacitor. It is, therefore, a differential method. Consider now hands being tested with no contamination: the voltage on the capacitor would fall eventually (at a pre-set negative voltage) causing a 'low' indicator to operate. With heavily contaminated hands being tested the voltage would rise eventually (at a pre-set positive voltage) causing the 'high' indicator to operate. Hands contaminated at intermediate levels would cause the voltage to fluctuate up and down with the usual statistical variations eventually operating either the high or low level indicator.

This parallel boundary method, as the authors call it, provides a considerable saving in time as compared with the usual method, and according to computations which have been carried out at AERE results in a saving of time by a factor varying from 5 to 7 times.

In urine tests, where counting for 8 hours is common, it is now proposed to introduce a preliminary sorting operation which uses an average sample time of 10 minutes for weak samples. The distribution of activity between samples is such that only about one sample in a hundred is expected to require the more accurate 8 hour measurement, and the average measurement time for samples of this type is thus reduced from 8 hours to an average of about 20 minutes.

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4. Process chemistry

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IT HAS BEEN A QUIET YEAR in the field of process chemistry and there are few highlights to report. This is not altogether unexpected in view of the great deal of work reported at the second Geneva Conference. Until that time, much of the work in process chemistry, especially that concerned with the processing of irradiated fuels, was still classified on security grounds. Each of the principal processes in use in the USA and the United Kingdom were described at Geneva and these are still in operation and will be so for some time to come. Present developments have been more concerned with improvements in detail rather than major changes in philosophy.

There continues to be much interest in the processing of raw materials, but perhaps the most important event in uranium processing has been the commissioning of the new plant at Springfields. The first step in processing the ores or concentrates, involves solvent extraction into TBP (tributyl phosphate) using large continuous multi-stage mixer-settler box contactors (*1, 2*). This is followed by a batch-operated fluidized bed Dryway plant (*3*) for deni-

tration of uranyl nitrate solution and fluorination of UO_3 to UF_4. Magnesium is now used in place of calcium in the metal reduction stage.

The fluidized bed technique has been discussed in many papers in the last year and, while its use in the USA and at Springfields represents a major advance in uranium processing, it is certain that more applications for this operation are likely to be found in the processing of raw materials, irradiated fuels and effluent in the future.

Irradiated fuel processing

The Butex plant at Windscale continues to process the UK's output of irradiated natural uranium fuel elements. A new separation plant is scheduled for construction at Windscale to process fuels from civil power reactors and from British built foreign power stations. Development has reached the stage where detailed design of the plant is well under way and this is being supported by a large experimental programme. Undoubtedly, this will be a process based on the use of TBP, diluted with an inert solvent, and using mixer-settlers in place of the gravity feed columns in the present plant—presumably basically similar to the processing plant at Dounreay and at Marcoule, which both use TBP and mixer-settlers. The new plant will have a greatly increased throughput and this has led to the necessity for parts of the process to be under strict criticality control. It is planned to make some of the later stages in the plutonium metal finishing plant continuous in operation. As it is hoped to make extensive use of salt-free steps, increasing use will be made of effluent evaporation techniques.

In the USA all major irradiated fuel processing plants are still based on aqueous methods—thus Hanford operates the Pusex (based on TBP) and the Redox (Hexone) processes. Most solvent-extraction studies in the USA and elsewhere are devoted to TBP, which has, on balance, the most satisfactory properties in extraction characteristics and irradiation stability. Alternative solvents, especially of the amine type, are under investigation and may turn out to be even more satisfactory for some applications.

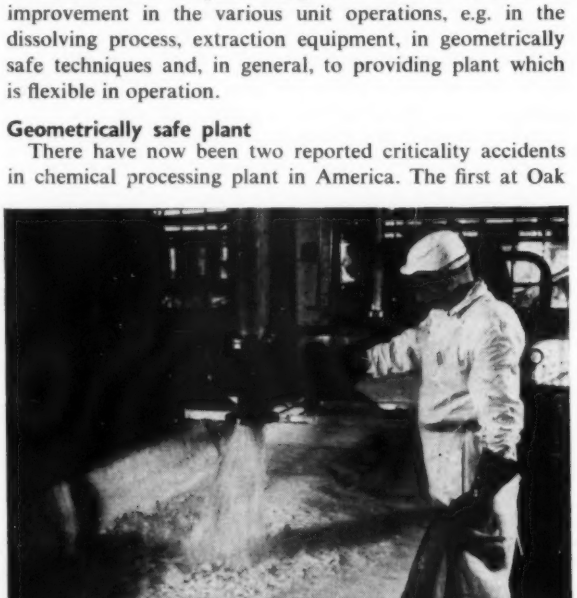
A great deal of American development work continues on mixer-settlers and on pulsed columns. It appears that both techniques find about equal favour. Both offer considerable advantages in improved extraction conditions and the choice for any particular plant seems to depend on which US laboratory plans the process. In the UK, the decision has been taken to devote most attention to mixer-settlers. A paper by Williams *et al* (*4*) reviews British work, whilst a paper by Rigon *et al* (*5*) reviews Oak Ridge studies on the scale-up of mixer-settlers. Roberts (*6*) has described the development of irradiated fuel processing in the USA—he has drawn attention to a large number of declassified reports which are now available.

A considerable American effort is still devoted to the development of methods for pyrometallurgical processing, but there is very much less interest in the UK and elsewhere. High temperature methods are only likely to become important when the fuel element is relatively simple and is also not liable to variation in design. The only plant under construction is that for EBR-2, where the fuel is to be processed by melt refining. The development work has been carried out at the Argonne National Laboratory. Many fast reactor fuels are complex, e.g. the Dounreay fast reactor fuel elements, and some are not yet of fixed design. For this reason, it would seem that aqueous methods of processing will continue to be of major importance in the foreseeable future.

Present trends in plant design are directed towards an improvement in the various unit operations, e.g. in the dissolving process, extraction equipment, in geometrically safe techniques and, in general, to providing plant which is flexible in operation.

Geometrically safe plant

There have now been two reported criticality accidents in chemical processing plant in America. The first at Oak



At the UKAEA processing works at Springfields, these Nutsch filters for ammonium diuranate, which have given surprisingly good service for years, are now being replaced by rotary filters

Ridge in the Y12 (*7*) plant, in which highly enriched uranium is processed, and the second at Los Alamos involving the working up of plutonium residues. The most important feature of both was that the accidents occurred under unusual operating conditions and so far there has been no accident in any process operating according to the designed flow sheet. These accidents have served both to underline the need for plant which is sufficiently flexible for processing a wide range of residue fissionable materials, and also to provide a big incentive to the design of geometrically safe equipment (see p. 118 this issue).

Economics of processing

Much existing plant for fuel processing was planned and built at a time when the major consideration was to get a process working irrespective of the cost. With the emergence of a large nuclear power programme in the UK, it is appreciated that the costs of processing raw materials, fabricating fuel elements and processing irradiated fuels, are important in assessing nuclear power costs. The main point that arises from this is that, if fuel processing costs are to be kept down, then the plant must be capable of dealing with the largest possible amount of fuels and at high throughputs. The most costly item in a separation plant is the building (and shielding) to house it and the cost of individual equipment is relatively small. These factors are now being actively studied and one outcome is the decision to process all the British civil reactor fuels in one large plant of new design. It is to be expected that more papers dealing with the economics of processing will appear in the near future as the large-scale generation of nuclear power gets under way.

Problem of effluent disposal

The most important event in the effluent field was the Monte Carlo Conference in November (see *Worldview* this month). This was concerned both with processes and with the environmental aspects of effluent treatment. Although little new in processes was reported, there was a great deal of discussion concerning the advisability of disposal to the sea. Despite criticisms, there does not appear to be any evidence for presuming that any danger arises from British methods of disposal. In fact, a very real attempt is being made to study the whole problem of waste disposal and its possible environmental effects. Thus plans have been made to investigate the effects of controlled small concentrations of radioactivity on natural food chains. This is to be carried out in specially constructed ponds at Windscale.

A considerable effort is being devoted to investigations into methods for 'fixing' highly active wastes, e.g. in glasses and by other methods. An American method, reported at Geneva, uses a fluidized bed for dealing with such effluent and the technique appears promising for large-scale application. These represent big advances over present methods for storage of highly active wastes and big changes in the techniques of effluent disposal are to be expected as a result of such studies.

Fission product separations

There seems to be no immediate plan for installing a large-scale caesium separation plant at Windscale. A temporary experimental plant produced sufficient caesium-137, from fission product wastes, for five sources of about 1400 curies. This work was completed in 1958 and it appears that future British large radiation sources will, according to present plans, rely on cobalt-60 produced in the Calder, Chapelcross and the civil power reactors. Very much larger caesium sources have been prepared in America (*8*). The Oak Ridge pilot plant is currently producing 200,000 curies of caesium per annum.

The last year has seen some interesting small-scale separations at Windscale. The extraction of some 100 grams of neptunium has been completed. The process involves the separation of neptunium from aqueous raffinates arising in the uranium purification cycle by a combination of solvent extraction, ion exchange and precipitation techniques. Similar separations for neptunium have been reported in the USA.

Protactinium, of the order of 100 grams, has also now been separated at Windscale by a method described at Geneva. This must be the largest amount of separated protactinium in existence. It was obtained from waste products from the Springfields uranium plant.

Another interesting element to have been separated in gram quantities is technicium. This has been extracted by ion exchange techniques from fission product wastes but no details of the process have been published.

Acknowledgment

The author would like to acknowledge all those with whom he has discussed topics referred to in this survey.

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5. Fuels and materials

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Irradiation behaviour of uranium

The use of natural uranium for the current series of CEGB reactors has sustained interest in the irradiation behaviour of uranium and its very dilute alloys. Work reported by Greenwood at AERE has shown that swelling due to fission product gases above 450°C can be explained by the enhanced creep of the anisotropic uranium matrix resulting from the superimposed intergranular stresses from thermal cycles of ±10 to 50°C. A tendency has been noted for the relatively abrupt formation of large bubbles in some samples for critical conditions of temperature and burnup. These large bubbles are usually associated with large swellings, depending upon the mode of nucleation of the gas bubbles. It is believed that crack formation is important at the bubble nucleation stage.

Work by Buckley at AERE and Stobo at Parsons indicates that the deformation caused in uranium by phase transformation cycling can be explained by the relative strengths of the alpha and beta or beta and gamma phases on either side of a transformation interface. It appears that the effect of partial transformation of a fuel element will not be serious unless more than 10–20% of the diameter is transformed, thus giving the possibility of a useful relaxation on the centre temperature of a fuel element.

British scientists, particularly Harding at AERE, and Lehmann in France, have shown the considerable importance of metastable phases formed when alloys based on the body-centred cubic gamma-phase of uranium are quenched. This work is not only systematizing the conditions under which variants of the gamma and alpha structures form, but is also showing the profound effect these structures have on metallographic and mechanical properties. Uranium-molybdenum alloys have been signalized for their irradiation stability by British, French and American workers, the more dilute alloys being claimed to have grain size stability and the more highly alloyed having enhanced swelling resistance. At Argonne National Laboratory, the use of similar uranium alloys containing all fission product elements present after high temperature reprocessing is still receiving considerable support for the EBR-2 reactor.

Plutonium research and technology

Work on plutonium is expanding in both fundamental research and the technology of plutonium fuels. Two topics

of particular fundamental interest are the large number of allotropic forms plutonium exhibits and the unusual behaviour of the face-centred-cubic delta-phase which exists between 320 and 450°C. Work by Lee and Mardon at Harwell has greatly increased our knowledge of the properties of the various phases including the delta-phase at temperatures down to 1°K. These have shown general similarity in behaviour among the relevant phases of uranium, neptunium and plutonium. The anomalous behaviour of the delta-phase of plutonium disappears when studied outside its normal range of stability, confirming that special electronic effects are operating in the region where delta and delta′ are stable. Mardon's work at AERE on the alloy systems of neptunium with plutonium and uranium has shown extensive solubilities in the complex low temperature modifications giving promise of a further understanding of these complex structures.

Studies of the technology of plutonium by Mardon and Poole have shown that a number of possible fuel materials for fast reactors and spike enrichment of thermal reactors exist. Uranium-molybdenum-plutonium alloys and a number of cermets based on PuO_2 have been shown to have irradiation and metallurgical stability. A liquid plutonium-cerium-cobalt alloy fuel has also been shown to have promise for the LAMPRE-type reactor concept.

Outside Britain, the plutonium fuel fabrication facility at Argonne National Laboratory has been formally opened and will be used to fabricate fuels on a semi-production basis. The Plutonium Recycle Test Reactor fabrication facility is also nearing completion at the Hanford Works and will match the ANL facility in its scope if not in engineering sophistication.

Thorium alloy systems

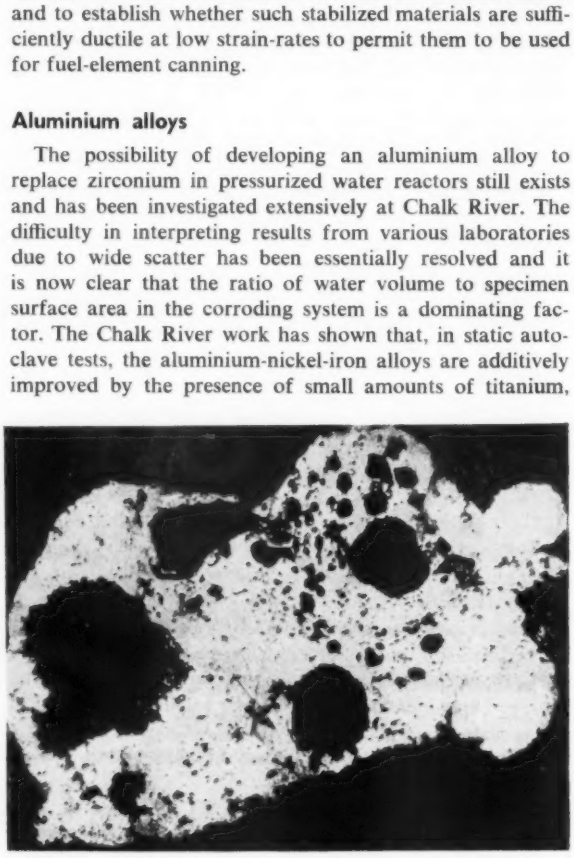
Information on the constitution of several thorium alloy systems has become available recently from the UK, USA, and USSR. Alloys studied include Th-Ce, Th-Pu, Th-Al, Th-U, Th-Zr, Th-U-Zr, Th-U-C, ThC-UC, ThC-ZrC and ThC-UC-ZrC. Several of these systems have possible applications as fuel element materials since unalloyed thorium has poor mechanical properties. As a first stage in the development of thorium-rich alloys with improved creep strength, the tensile properities at room and elevated temperatures and hot hardness characteristics of thorium and several thorium-rich alloys have been investigated in the UK while the mechanical and physical properties of thorium-rich Th-U alloys have been studied in detail by Bentle.

Magnesium alloys

Recent work in this country on magnesium-based canning alloys has been concerned with recrystallization and failure effects in Magnox A12 and ZA. The latter alloy, containing approximately 0·60 wt% of zirconium, is also being considered as an alternative canning material to Magnox for some particular applications. Failure associated with cavitation, which can occur under certain stress conditions over the temperature range 200 to 400°C, is currently receiving attention, and efforts are being made to correlate failure mechanisms with grain-boundary effects and with grain-size stability. The control of grain-growth by zirconium additions, as in ZA, is being studied, and recently published French work has indicated that almost complete grain-size stability can be achieved by heat-treating such alloys in hydrogen. More work remains to be done in order to determine the causes of these effects, and to establish whether such stabilized materials are sufficiently ductile at low strain-rates to permit them to be used for fuel-element canning.

Aluminium alloys

The possibility of developing an aluminium alloy to replace zirconium in pressurized water reactors still exists and has been investigated extensively at Chalk River. The difficulty in interpreting results from various laboratories due to wide scatter has been essentially resolved and it is now clear that the ratio of water volume to specimen surface area in the corroding system is a dominating factor. The Chalk River work has shown that, in static autoclave tests, the aluminium-nickel-iron alloys are additively improved by the presence of small amounts of titanium,



This typical section of an irradiated uranium specimen increased in volume by 146% after 0·34% burnup at 600°C. Subjected to severe temperature fluctuations during irradiation, the specimen contains large holes as well as intermediate and fine porosity (× 15)

beryllium and zirconium. In dynamic loops, however, the differences in corrosion behaviour between the various alloys are very much less and the advantages of alloying are reduced. Experiments on inhibition indicated that SiO_2 is effective in neutral solutions when present in the range 300–1000 ppm (phosphoric acid is effective only at pH values of about 4). Chalk River opinion is that aluminum might not be competitive with zirconium even on a straight economic basis.

Harwell work by Wanklyn and Wilkins on dry steam corrosion showed that aluminium-nickel-iron alloys are reasonably good to temperatures somewhat above 300°C but between 400°C and 500°C heavy penetrating attack occurs. On the other hand SAP is good at high temperatures but poor up to about 300°C. The combination of alloying with the SAP principle has been tried with a 1% nickel alloy and the results indicate that good corrosion resistance is obtained over the whole temperature range of interest.

Properties of beryllium

The development of the prototype Advanced Gas Cooled Reactor, in which beryllium is the proposed canning

material, has stimulated interest in the fabrication and properties of the metal.

The effects of heating on beryllium irradiated at 70°C to an estimated total dose of $7{\cdot}6 \times 10^{21}$ nvt fast neutrons/cm² has been reported by Rich, Redding and Barnes, and Ells and Perryman. The irradiation caused considerable hardening of the beryllium and a helium content of the order of 10 cc per cc of metal at NTP had been formed, mainly by the (n, 2n) reaction. Heating to above 600°C caused bubbles of helium to appear at the grain boundaries with an associated fall in hardness and density.

The suspected phase change in beryllium at high temperature has been identified by Moore and Martin: at about 1250°C X-ray analysis showed that the crystal structure of beryllium changes from hexagonal to body-centred cubic. A detailed analysis of the effects of texture and grain size on beryllium sheet with room temperature tensile elongations of up to 40% has been published by Greenspan. This highly oriented sheet cannot, however, accommodate complex plastic deformation.

Constructional steels

The problem of brittle fracture in steels has received, and is still receiving, considerable attention both theoretically and experimentally. The importance of this problem in the nuclear power industry is highlighted by the recent failure during construction of the 4 in. thick pressure vessel for the French reactor EDF-1. A brittle crack originated at a weld in the lower section of the vessel and propagated for a distance of about 30 ft.

Cottrell has published a new theory of brittle fracture in which it is suggested that crack propagation, and not crack nucleation, is the difficult stage in fracture. According to this theory a crack can be nucleated in body-centred cubic metals by coalescence of two edge dislocations. Complete fracture occurs if the crack size is greater than the Griffith value and if it is less stable, microcracks are formed blunted by plastic deformation. A ductile-brittle transition occurs if the following two relations are satisfied:

$$(\sigma_i d^{\frac{1}{2}} + ky)ky = \beta\mu\gamma \qquad \ldots (1)$$

where

$$\sigma_i = \delta_y + kyd^{-\frac{1}{2}} \qquad \ldots (2)$$

where σ_i is a measure of the frictional resistance to the movement of dislocations, $2d$ is the grain size, ky is a measure of the dislocation locking stress, σ_y is the lower yield stress, β depends on stress distribution being unity for uniaxial tension and $\frac{1}{3}$ at the root of a plastic notch in hydrostatic tension, μ is the shear modulus, γ is the effective surface energy.

It has been shown that in an En 2 steel (0·15% C, 0·6% Mn, 0·12% Si) irradiated at 50–100°C, the principal effect of irradiation is to increase the term which unbalances equation (1) and raises the transition temperature. For the En 2 steel with a grain size of about 1000 grains/mm² the increase in transition temperature is roughly proportionl to the cube root of the neutron dose:

$$\triangle T = 17{\cdot}5\phi^{\frac{1}{3}}$$

where ϕ is the integrated neutron dose in units of 10^{18} thermal n cm^{-2} in positions where the ratio of thermal to fast flux is about 10:1.

Uranium oxide

The available data on the behaviour of UO_2 as a reactor fuel is based mainly on Canadian and American information. Experience there indicates that high density ($\sim$ 10·4 g/cc) stoichiometric UO_2 is basically a satisfactory reactor fuel providing it is sheathed in a suitable can. Most of their irradiation work however has been carried out in support of water-cooled systems.

Experiments so far have been concentrated on relating the fuel element ratings with temperature distribution through the fuel elements, consequent structural changes, and fission gas release with the associated build-up of pressure within the can. Due to the uncertainty of values for the thermal conductivity of UO_2 and its variation with temperature, particularly after irradiation, it has been found convenient to use a parameter $\int kd\theta$ to specify the irradiation condition as this integral can be evaluated knowing the fuel diameter and rating.

Although this allows comparison to be made for elements under similar conditions, to translate these results to a different system some specific temperature indication must be available, e.g. fuel surface temperature. This is particularly important when considering the release of fission product gases. Canadian results would indicate that, providing the centre fuel temperature is kept below 1500°C, corresponding to a value of $\int kd\theta$ of 30 watts/cm for a fuel surface temperature of 400°C, less than 1% of the gas will escape for a burnup of 10,000 MWd/T.

The Canadians have carried out a larger number of very short term irradiations ($\sim$ 3 min) and have observed most of the phenomena seen in high burnup experiments, that is, in the high-rated fuel elements, radial cracking, grain growth and centre melting. This type of irradiation experiment is extremely useful for studying the effects of variables, e.g. fuel density, fuel/can gap on the value of $\int kd\theta$ for grain growth or centre melting. It remains to be proved how long-term burnup effects would alter the value of the integral.

6. Applied irradiation

by A. G. MADDOCK, M.A., Ph.D., D.I.C.
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APPLIED RADIATION has retreated into the laboratory. In the several meetings dealing with this subject during the last year. the FAO Conference at Harwell at the end of 1958 (*1*) the mid-summer conference at MIT and the I.A.E.A. Conference (*2*) at Warsaw in September, an atmosphere of pessimism has submerged the hopes of immediate large-scale application of irradiation for the preservation of food. Clearly a prolonged period of further investigation will be necessary before industrial application becomes likely. In addition to doubts as to the economic possibility of preservation by irradiation, investigations released at the conferences show that the nutritive value of the product and the absence of harmful effects of the irradiation must be questioned. However, it is quite likely that the somewhat irrational enthusiasm for this application, common a year or two ago, has simply been replaced

by slightly less unreasonable doubts engendered by the most recent laboratory results. The only acceptable basis for this industrial application is the combination of a satisfactory economic analysis with promising and reliable results from a lengthy and comprehensive series of laboratory tests.

The outlook for radiation sterilization of pharmaceuticals and similar products seems rather unfavourable. Not a great deal of new information has appeared during this year. The routine sterilization of sutures by radiation by the Ethicon Corporation of New Jersey remains one of the very few actual plant scale applications of radiation and it is stated to be economically competitive with the more conventional methods (*3*).

Limited chemical applications

The use of radiation in the chemical industry remains very limited. In most cases, products possessing similar properties can be produced more cheaply by alternative methods: radiation is effective through radicle production and these can usually be generated by alternative procedures. It has been repeatedly observed that an economically competitive radiation synthesis must either have a very high yield, or G value, involve materials of very high molecular weight or produce a novel product. Applications in the plastic field fall into the second of these categories. The likelihood of eventual industrial application on a large scale still seems high in this field, although alternative conventional methods of production often seem to follow the discovery of promising radiation products. Attention is being directed especially to radiation-induced copolymerization (*4*). So far, there have been very few examples of novel chemical products so that it is interesting to report that Henglein described a new compound, first prepared by a radiolytic reaction at the Warsaw meeting.

Amongst a wide variety of publications dealing with different aspects of applied irradiation, attention is drawn to the following points and papers. The controversy over the relative economic merits of accelerators and isotopes for irradiation has abated to some extent. It is generally agreed that accelerators are cheaper at present for thin samples but that isotopes or fuel element sources are, or will be, cheaper when the sample size demands a penetrating radiation. A detailed and generally unfavourable analysis of the use of a circulating loop running through a reactor to provide a field of purely ionizing radiation, using a reactor, has been made (*5*). A convenient review of the principal methods of dosimetry has appeared (*6*) and a description of the new irradiation facility at Wantage (*7*).

Isotope techniques still spreading

Although the spectacular progress of recent years has not been maintained, radioactive isotope techniques continue to spread over a wider and wider cross-section of industry. A recent statement of the USAEC reveals contracts they have placed for investigation of applications in the textile, detergent, petroleum, food processing, metallurgical and gas industries. Early in the year, a translation of a Russian review appeared which summarized much of the Russian work on metallurgical applications and includes a very convenient compendium of references to this work up to 1957. Some of the simplest applications, such as flow and mixing studies, remain the most profitable. An interesting paper shows how a continuous recording of the activity leaving a system after injection of a pulse of active material at the input stage can be used to detect leaks in the system (*8*).

Industrial radiography continues to employ more and more sources and many welded devices receive routine inspection by radiographic methods with isotope sources. It still seems doubtful whether such users can consume any appreciable proportion of the huge output of Cs-137 that has been promised for the near future.

Because of its negligible radiotoxicity (*85*) krypton has considerable possibilities for industrial application. As a rare gas forming virtually no compounds, it is rather inconvenient to handle. An interesting proposal has been made to utilize the clathrate compound it forms with quinol. If quinol is crystallized from solution in the presence of a considerable pressure of krypton, a compound separates which contains krypton atoms trapped in the cages formed by the hydrogen bonded quinol lattice. Under favourable conditions, the composition approximates to one atom of krypton to three molecules of quinol. Even in high vacuum, this compound liberates a negligible proportion of the krypton. Provided the compound has the necessary radiation stability, it should provide a novel solution to the problem of handling Kr-85 (*9*).

Activation analysis is another application of radioactive techniques that makes steady, if unspectacular, progress. During the year, a successful conference on this subject was organized by the IAEA in Vienna; in addition a very valuable review has been published by Atkins and Smales (*10*). Using neutron activation the method is especially satisfactory for the determination of Dy, Eu, Au, In, Mu, As, La, W, Cu, Ga, Ta, Na, Cs, Co, P, Rb, Ba, Hg, Cl and U. However, many applications of the technique using other bombarding particles or alternative reactions to the (n,γ) reaction are finding use. Oxygen may be determined directly in organic compounds using a betatron and the $^{16}O\ (\gamma,n)^{15}O$ reaction. Both oxygen and carbon can be determined in beryllium by the same technique and the former element can also be determined by fast neutron irradiation (*11,12*). Both methods are suitable to the determination of tens of parts per million of these elements in beryllium—a notoriously difficult estimation by conventional methods. Isotopic composition can also be determined in this way in some cases—U-235/U-238 ratios can clearly be estimated by slow neutron irradiation and measurement of a fission product activity. A less conventional example (*10*) is the determination of the ^{16}O content of water by slow neutron irradiation of a solution of a lithium salt in the water, followed by measurement of the ^{18}F activity $^{6}Li(n,\alpha)T,^{16}D(t,n)^{18}F$. Such charged particle reactions are peculiarly suitable in the determination of light elements.

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13. *Analyst* in press

Cross Section by GRACCHUS

THE LAST few pre-criticality hours must have been pretty tense at Dounreay last month (and at NUCLEAR POWER's editorial offices too, judging by the speed of their appearance with features on it). I must admit I wasn't present at the Dounreay ceremony but hereby pass on a couple of items from one who was.

As the fast reactor approached criticality a chart recorder was plotting out one of the vital curves. Just at the crucial (and critical) moment the many eyes fastened on it saw the curve vanish. The ink supply had failed. In order to find out what the reactor was up to one of the staff had finally to resort to squeezing in a few drops by means of an eye dropper. This should have been enough for one startup in the way of silly mishaps, but after a year of fiddling about the reactor was evidently determined to have its moments of drama, and a minute or two later the alarm tripped. Bells and red lights sent everyone moving rapidly to cover until it was realized that only the electrical system was at fault. Apart from these bits of custard pie stuff the whole operation went off very smoothly indeed, and I think congratulations to all the staff are in order.

I WONDER if I am more touchy than the average man about units? My own troubles started at school where I first lost sight of land during the sixth form physics class, and doubts were only increased by a university engineering course. When I had at last achieved an unsteady equilibrium by floating with one foot on each of the electrostatic and electromagnetic systems, as it were, with a tow-rope to the foot-pound seconds, I was finally submerged by the introduction of metre-kilogramme-second units—rationalized, or was it unrationalized?

Since then I have concentrated on the ordinary metric system and defend it against all comers (it is the only one I can work in with safety). I violently disapprove of any further innovations and was, therefore, rather irritated to come across megawatt days per *ton* in a recent Atomic Energy Authority publication. The figures were included in a paper by Sir John Cockcroft and referred to the burnup of Calder Hall fuel elements. Wondering whether the normal *tonne* was intended, I phoned the AEA. They did not know, but they did ask Sir John's private secretary. She did not know; when asked to check against the original paper she said that Sir John had got it. Further search for information resulted in the news that Sir John could not be contacted as he was away. These units will finish us all, in the end!

ATTENDING the second international conference, in Hamburg, for the application of nuclear power to marine propulsion, I felt very lonely; apart from one lone Rear Admiral, retired, with a watching brief for a European organization, nobody represented, let alone spoke up for, the British merchant services. Of over seven hundred people attending, predominantly shipbuilders or shipowners, the largest contingent, outside of Germany, came from Japan.

Over the past seven months I had heard that the Atomic Energy Authority had (1) put forward proposals to the Galbraith Committee for the application of Advanced Gas-cooled reactors to marine propulsion; (2) withdrawn them; (3) put them in again.

I had to go to Hamburg to find out what the AEA has been doing and learned that at least up until last May their work was very comprehensive indeed. An extensive review of various systems was given at the conference together with a detailed cost estimate for a range of AGR's. It is rather surprising that this information was not made available in the UK first.

ONE of the best organized official ceremonies I have been to for a long time was the inauguration of Jason at Hawker Siddeley Nuclear Power works in Slough. A star-spangled guest list of 150 and a large crowd of journalists assembled to watch Sir John Cockcroft bring the reactor up to power. To attempt to squeeze everyone into the reactor building—a handsomely converted hangar—was obviously out of the question. So a large marquee was put up next door and the ceremony relayed on a series of closed circuit television sets. This was backed up by a large working model of the reactor, on which the steps to criticality were demonstrated, and a giant log-power meter. To the accompaniment of a most professional running commentary from the reactor building, we saw the source driven in, safety rod out, water level up, a stringer inserted containing a magnesium specimen, fine control rod withdrawn, divergency warning, and reactor operating lights on. When the power reading was taken the microphone was handed to Sir John who said, 'Well, I think the reactor is now critical'.

While Sir John and Hawker Siddeley officials returned to the platform the magnesium specimen was irradiated and after half-an-hour was unloaded and sent direct to Slough College of Further Education. From the platform Cockcroft said, 'I am glad to have had the opportunity of demonstrating my skill in starting up reactors. You will have noticed through the T.V. that everything has gone perfectly and safely'. And indeed it had.

He went on to poke a little gentle fun at small-time reactor owners: 'In looking round the world we see that it is now considered just as essential for a country, however small, to have at least one research reactor as to have a national air line or a T.V. station'.

I SUPPOSE no-one but the present chairman of the Central Electricity Generating Board, when making a plea for a more sympathetic approach to the Board's problems in siting its power stations, would present the opposition with some objections it hadn't thought of. Addressing the Royal Society of Arts recently he argued that it didn't really matter whether a proposed site was beautiful or not: that it was a piece of hitherto unbuilt-on countryside was sufficient objection in itself. It was useless to claim that on the broad promontory of Dungeness a nuclear power station would provide a dominating and challenging feature, he thought. 'The man who goes to fish from the beach at Dungeness doesn't worry that it is featureless. He goes precisely because it is deserted. The last thing he wants there is a challenge from man. Objection on these lines is seldom voiced at our inquiries. I doubt whether the average man is conscious of it. The main objections, therefore, come through bodies such as the National Parks Commission and the Conservancy Societies.'

On record

One of the first questions a shipowner thinking in terms of a nuclear-powered vessel must ask is: 'When will fuel be available for commercial use; what will be the price to be paid for it; will supplies be assured over the years?'—C. C. Pounder, Vice President, I.Mar.E.

The second international conference on marine propulsion by atomic power recently gave an opportunity for discussion on national nuclear ship programmes

Prospects for nuclear powered ships

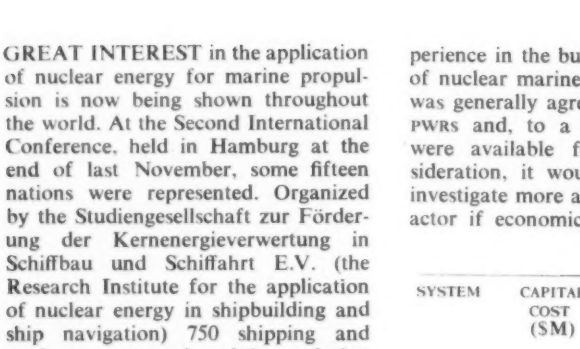
Report from Hamburg by C. E. STEINER, NUCLEAR POWER

GREAT INTEREST in the application of nuclear energy for marine propulsion is now being shown throughout the world. At the Second International Conference, held in Hamburg at the end of last November, some fifteen nations were represented. Organized by the Studiengesellschaft zur Förderung der Kernenergieverwertung in Schiffbau und Schiffahrt E.V. (the Research Institute for the application of nuclear energy in shipbuilding and ship navigation) 750 shipping and nuclear experts reviewed the work that has already been carried out and discussed possible developments.

To date only the Americans and Russians have had any practical experience in the building and operating of nuclear marine propulsion units. It was generally agreed that while OMRs, PWRs and, to a lesser extent, BWRs were available for immediate consideration, it would be necessary to investigate more advanced types of reactor if economic operation is to be achieved in the not too distant future. The plant most likely to be successful in this respect is the gas-cooled closed-cycle gas turbine type. In an evaluation of the different propulsion systems, the Nuclear Projects Office of the US Maritime Administration have estimated the relative costs over the next fifteen years for a 30,000 shp unit.

US estimated costs for 30,000 shp vessel

SYSTEM	CAPITAL COST ($M)	OPERATING COST (mills/shp/h)	EFFICIENCY (%)		FUEL COST (mills/shp/h)	
			1965	1975	1965	1975
BWR	10·6	9·50	27·4	31·0	2·51	2·27
PWR	12·0	12·18	23·6	32·0	4·46	3·58
OMR	10·9	10·77	24·0	29·0	3·05	2·62
GCR	10·9	9·17	35·0	42·0	2·04	1·79



THE AEA's DESIGN. A marine AGR for a 22,000 shp tanker of 65,000 tons.

1. 6 in. polythene
2. 6 in. lead
3. containment access
4. top shield
5. containment structure
6. containment space (CO_2 atmosphere)
7. charge face
8. steam turbine blower unit
9. internal neutron shield
10. heat exchanger
11. reactor core
12. heat exchanger
13. 14 in. steel shot concrete containment shielding
14. bottom shield
15. water shield tank
16. 27 in. water
    14 in. steel primary shield, and
17. pressure vessel

The operational advantages of the GCR are that efficiency can be maintained over 50–100% load range; rapid startup and load changes are feasible; and core thermal capacity can absorb initial after-heat. The maintenance advantages of the GCR lie in a long reactor life; simple one-fluid systems; a non-wetting coolant; no induced activity in the coolant; and no corrosion by the coolant. Further, the system offers advantages in safety in that emergency cooling by air and sea water could be effected; and the coolant is chemically inert.

While not going quite as far as the Americans, the UK Atomic Energy Authority, in a paper by R. P. Kinsey and H. W. Bowler, presented by S. Fawcett, Deputy Director of Reactor Engineering, reviewed their work between January 1958 and May 1959. The feasibility and economics of nuclear marine propulsion for a 65,000 dwt tanker of 22,000 shp were examined and five systems were evaluated in connexion with the Galbraith Committee (see NUCLEAR POWER, June 1959, pp 89–91 and August 1959, pp 76–81). Estimated costs were for such

ESSO BOLIVAR. The first Western European merchant vessel to be nuclear propelled. This 15,000 ton tanker is to be fitted with an OMR by a Hamburg group of shipping firms

a vessel operating 300 days per year at full power.

Mr. Fawcett did not think that the gas-cooled systems would prove economical for a long time and suggested meanwhile that improvements could be made to the PWR, BWR and OMR types. He said that PWR's could use lower pressures to enable boiling within the core to take place; the form factor could be improved to boost economy; the addition of heavy water would improve neutron economy; and the number of control rods could be reduced by using burnable poisoning.

Direct cycling could reduce the cost of BWR's but special care would have to be taken to prevent contamination.

The only suggested improvement in OMR's was that put forward earlier in the year. That is, to improve the fuel elements, especially the canning, and here beryllium could possibly be employed.

It is the AEA's opinion that ultimate fuel costs should come down to between 0·25 and 0·35d/shp/h but so far no definite plans have been made in the UK to build any form of mercantile nuclear propelled vessel.

UK estimated costs for 22,000 shp tanker

	HULL (£M)	PROPULSION (£M)	REACTOR (£M)	TOTAL ANNUAL Operating (£M)	FUEL COSTS Pence/shp/h
Conventional ship	2·90	1·20	—	1·055	
AGR	2·90	1·07	3·33	1·569	0·437
GCHWR	2·90	1·07	4·03	1·746	0·549
PWR	2·90	1·12	1·98	1·454	0·561
BWR	2·90	1·07	1·53	1·361	0·535
OMR	2·90	1·12	1·58	1·432	0·568

Practical applications

The advances made in marine propulsion over the past two years were clearly shown at the meeting in that at the previous conference in 1957 the discussions were mainly of a theoretical nature but now the work was centred on constructional and navigational problems. Projects scheduled to start in the immediate future included marine installations in Germany, Japan and the Netherlands.

The Hamburg group of shipbuilders and owners forming the Research Institute have taken up an option on the *Esso Bolivar*, a 15,256 dwt tanker and are going to install an OMR propulsion unit. This will be built by Interatom, a German company, jointly formed by Demag and Atomics International and scheduled to be installed in 1962 ready for sea trials in 1963.

In Japan, Mr. M. Yamaguchi of Mitsubishi Shipbuilding & Engineering Co. Ltd. said, five classes of vessels had been evaluated and proposals submitted to the Japanese Atomic Energy Commission by a Special Committee on Nuclear Ship Propulsion. These were:

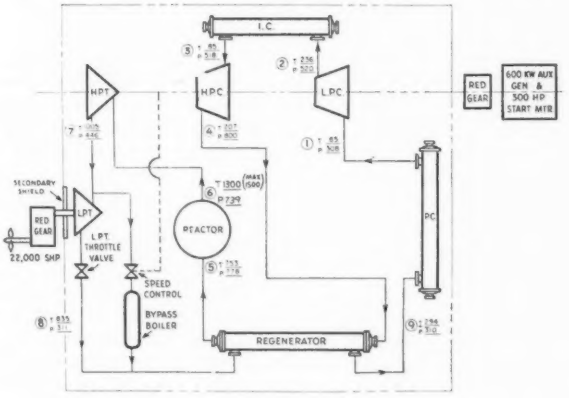
TYPE	SHAFT HORSEPOWER	TONNAGE
Emigrant	22,000	17,000 (gross)
Experimental	8,000	4,000 (gross)
Oil Tanker	40,000	45,000 (cargo capacity)
Oil Tanker	20,000	20,000 (cargo capacity)
Oil Tanker	10,000	20,000 (cargo capacity)

It is proposed that construction of the small experimental ship will be started early in 1960.

The Netherlands, said J. P. Hulsman, a director of Stichting Kernvoortstuwing Koopvaardijschepen, the SKK, had concentrated their marine work in his organization which is made up of both shipbuilders and owners. Like Germany, the SKK proposes to first install a reactor in an existing tanker. The project, however, does not envisage the use of this plant for propulsion but merely to power auxiliary services while at sea. The object of this arrangement is to allow the tanker to operate as an economical unit all over the world.

Another project in Holland is for a 60 MWt PWR and Reactor-Centrum Nederland, RCN, have coöperated. The design study has been completed and detailed work is now in hand. Construction is scheduled to start in 1963 and operations to commence by 1965/66.

In addition to work on these new projects, a programme has been developed in the United States for the NS *Savannah*, launched on July 21, 1959. Mr. Ralph W. Deuster of the Babcock & Wilcox Co. said that before this vessel was ready to assume full duty in the US Merchant Fleet a vigorous test programme would be completed. A Combined Test Committee, CTC, had been established with members from the Maritime Administration, the AEC, the New York Shipbuilding Corp., Babcock & Wilcox and States



THE AMERICAN MGCR. The prototype reactor will operate with a constant-speed turbo-compressor running at 12,200 rev/min. In this flow diagram all temperatures, T, and in °F and pressures P, in psia

Marine Lines Co., who are to be the eventual operators. The programme will be in six phases.

Phase One—at present being carried out—preoperational integrity tests.

Phase Two—when all equipment except core is ready—systems will be operated at rated pressures and temperatures, using a supplementary heat source.

Phase Three—critical and zero power testing. First criticality is expected to be achieved during late spring 1960.

Phase Four—sustained reliability operations. This will form the basis for authorization of sea trials.

Phase Five—sea trials.

Phase Six—limited commercial operation, expected to last about two years.

Mr. Deuster stated that Babcock & Wilcox were already in a position to proceed immediately with the construction of PWR's for marine purposes and which have considerably improved performance.

GEESTHACHT RESEARCH STATION. At this establishment devoted to nuclear marine propulsion, the 5 MW FRH reactor is the principal facility

Gas-cooled reactor plans

Dr. William I. Thompson introduced the Maritime Gas-cooled Reactor, (MGCR) Programme which is being carried out by General Dynamics' General Atomic and Electric Boat Divisions and is sponsored jointly by the United States AEC and Maritime Administration. The system couples a GCR to a closed-cycle gas-turbine power plant and aims both at attaining higher temperatures from the nuclear source and using these higher temperatures more efficiently. Helium will be employed as the coolant and beryllium oxide will be used for both the moderator and reflector. Two types of fuel elements, one heterogeneous and the other semi-homogeneous, have been considered. The loading will have a 5% enrichment and an anticipated burnup of five years at full power.

The development of the MGCR is scheduled to be made in three stages. A land-based 50 MWt prototype will first be built, the basic design of which has now been completed and according to the present schedule, test operations will start early in 1964. This unit will operate at a maximum pressure of 800 lb/in² and at a reactor outlet temperature in the range of 1300°F to 1500°F. At the lower temperature, the reactor is anticipated to achieve a basic cycle efficiency of 32%.

The second stage will be the construction of the first seagoing version of the MGCR, to be known as the Mark 1, which will be operated with higher outlet temperature and working pressure than the land-based unit and aims at achieving a basic cycle efficiency of 37%. It is expected that the Mark I will be competitive with the then current oil-fired ships.

The MGCR Mark II will form the third stage and will combine the advantages of experience gained with the earlier reactors and advances in materials and turbomachinery. The anticipated 40% or higher thermodynamic efficiency will be greater than that of any other marine power plants of comparable power rating.

Reviewing the GEC/Simon-Carves GCR marine project, Mr. M. C. Hartnell-Beavis, while omitting any reference to detailed capital or operating costs, said that eventually GEC expect to get the fuel costs down to between 0·17 and 0·19 pence/shp/h. Anticipated improvements would be in the development of more efficient canning materials. In two years' time, graphite for this purpose should be available which by new methods of fabrication would be impermeable and not simply impregnated.

Research facilities

The Hamburg Institute is the first organization to operate a research reactor devoted solely to the study of marine propulsion. This is the 5 MW FRH swimming pool reactor, at Geesthacht on the River Elbe near Hamburg, and has four special pools and enlarged irradiation cells suitable for testing large fabricated sections applicable to marine installations.

In Japan the 46·7 MWt BWR of the Atomic Energy Research Institute will also be employed on marine propulsion research. At other centres in Europe, specialized research is now in progress on different components.

The French Atomic Energy Commission are concentrating their efforts on producing fuel elements with the maximum possible density for high temperature reactor applications. Early in 1960 they are bringing dynamic testing cells into service which will simulate the anticipated service conditions that will be encountered in marine installations. The research reactor Pegasus will also be used on this work and eight independent gas loops are being installed.

In Switzerland, W. Spillman, of Escher Wyss A.G., said that for a long time they have been working on the development of large turbo-compressors. In this field they have, he stated, been working with helium and other gases suitable for closed-cycle systems Operating temperatures have been between 400°C and 800°C and already a 11,300 hp plant has been developed.

German evaluation studies of existing and new marine propulsion systems were reviewed at the conference.

The work carried out at the Hanover Technical High School, described by J. Busch, was divided between gas-turbine development and reactor design. For evaluation purposes these two sections are combined and it appears that such units are not economically acceptable for power ratings of 10,000 hp. At present 20,000 hp plant would be the acceptable smallest. Gases, to reduce corrosion problems, are being investigated. Studies are being made of a 15 MW project employing helium/neon gas-cooling and the use of carbon dioxide as a coolant when working at a pressure of 40 atmospheres. Another member of the Hanover staff, Dr. K. Bammert said that gas turbines are now becoming competitors to steam turbines.

Two other designs being studied are a 60 MW BWR developed by the Allgemeine Electrizitäts-Gesellschaft for the Deutsche Werft A.G., and a PWR by Siemens & Schuckert of Erlangen for the Howaldtswerke of Kiel.

In Scandinavia work is being directed towards the more maritime aspects such as how the various reactors will operate under heavy sea conditions.

On the other side of the Baltic, the *Lenin* has completed sea trials and has now been put into service.

At the recent meeting of the American Nuclear Society, most of the discussion centred round the technology of the four power reactor types likely to prove practicable in the USA. Here is a report from Washington by a British observer

America evaluates reactor types

by G. W. K. FORD, M.A.
Reactor Division, A.E.E., Winfrith Heath

PERHAPS THE MOST POPULAR lecture series of the meeting was the presentation of the latest evaluations of the four design studies which were sponsored by the USAEC to assess the economic potential and practicability of nuclear power plants based on pressurized light water (PWR), boiling light water (BWR), organic cooled (OCR) and heavy water moderated (HWR) systems. The ground-rules for these studies were based upon a hypothetical but practicable site on which the station would be built, ability to start construction in mid-1960 with a guarantee that all research and development could be completed to a schedule properly linked to the construction programme, and an output power of some 300 MWe. The AEC's contractors each interpreted the assignment somewhat differently, in particular making varying assumptions about the permissible amount of research and development and the attainable fuel burnup; the HWR study was not originally part of the comparative study plan. However, by making appropriate adjustments, the AEC's evaluation team were able to make all four of the studies more or less directly comparable. Although the AEC evaluation report was issued during the summer, further re-appraisal had been made by the time of the ANS meeting. (Power cost breakdowns derived are given in the US section of the World Review in this issue.)

HIGH EFFICIENCY PWR

The PWR study was carried out by Stone and Webster Engineering Corporation and Combustion Engineering and reported on at the meeting by J. B. Anderson (Figure 1). It was considered to be the most developed design of the four, having been carried to a greater degree of detail both in engineering and cost estimates. Essentially, it has a two-zone core, 2·6% U-235 inner zone, 3·4% outer zone, with zones about equal in size, 56 tons of uranium as UO_2 fuel pellets clad in stainless steel, burnable boron poison, average burnup 13,000 MWd/T (25,000 max) giving a core lifetime of 3½ years without re-loading or re-adjustment of fuel at 80% load factor. The design as presented is for 236 MWe net, but it was claimed that the design could be extended to produce 300 MWe. The overall plant efficiency is expected to be 34·5%, which is high for a PWR, and is achieved as a consequence of a high primary coolant outlet temperature of 600°F. This is in turn dependent upon a design which permits bulk boiling to take place in the core, the design burnout ratio being 2·9: a ratio of 2·0 is considered acceptable. [Burnout ratio = (heat flux at which burnout occurs for given flow conditions)/(peak heat flux in the core)].

An important design feature in this core is the neutron rectifier control rod, which, coupled with a fuel-element 'tail' and the burnable poison, enables the control system to cover the very large change in fissionable material content which is required for the high burnup and the long reactivity life-time. This device consists simply of a hexagonal tube of Ag-Cd-In alloy of external dimensions similar to one of the standard hexagonal fuel element assemblies. To reduce reactivity a fuel element tail in the control position is lowered out of the core leaving water in its place surrounded by the hexagonal absorber tube to which the element is attached. The absorber tube absorbs 100% of the incident thermal neutrons in the normal way, but epithermal neutrons from the core pass through the tube wall and into the water volume. There the majority are slowed down and in turn absorbed by the absorber tube before they can escape.

In this way the control surfaces are more efficient than the normal cruciform type since as many as 10% of the neutron population in a PWR may be epithermal. Furthermore the control effect extends further into the core from each control rod since epithermal neutrons travel further through the core before absorption than can thermal neutrons. The double effect of first, reactivity-reduction as a result of the presence in the core of an absorber, then reactivity-enhancement by replacement of the absorber by fuel,

THE A.N.S. MEETING

Held in Washington from November 4–6, the 1959 winter meeting of the American Nuclear Society was attended by nearly 1000 delegates, of whom 600 were members of the Society. Papers presented totalled over 200 and were divided into four main sections: power reactor designs and economics; metallurgy, chemistry, fuel element design; reactor physics experiments; mathematical techniques. Here we concentrate on reactor designs and technology

Four AEC design studies—principal data

REACTOR SCHEME	CORE PRESSURE lb/in²	PRESSURE DIA. ft	VESSEL THICK in.	COOLANT OUTLET °F	MAX CAN TEMP. °F	SECONDARY PRESS. lb/in²	STEAM TEMP. °F	OVERALL THERMAL EFFIC. %	POWER COSTS, mill/kWh Authors	AEC	AEC 'future'
PWR	2000	10½	9	618	650	1050	545 ds	34·5	8·26 to 7·0	8·3 to 7·3	7·9
BWR	1015	12½	5·4	546	590	950	540 ds	31·2	8·0 to 8·6	8·9 to 9·4	6·8
OCR	27	13½	1·5	675	850	640	650 sh	29·6	7·31	8·3 to 8·8	7·1
HWR*	(Pressure tube design)			515	550	750	510 ds	25·1	12·6	12·5†	9·0†

* All data for HWR refers to a 200 MWe design: other schemes 300 MWe
† AEC forecasts for 300 MW D_2O moderated plant, natural uranium, not necessarily of boiling type.

enables a wide range of control to be achieved with a relatively small number of control units.

DIRECT DUAL CYCLE BWR

This plant design, described by F. C. Reichle of Ebasco Services Inc. and W. A. Hartman of the General Electric Company, was essentially based on the Dresden power demonstration reactor, and for this reason was not developed to the degree of detail of the PWR design. It is a direct dual cycle design, in which the steam-water mixture generated in the core flows, under the action of the forced circulation pumps, into a separating drum; from there the dry saturated steam flows to the first stages of the single turbine, the water passing on to secondary steam generators where lower pressure steam is generated for admission to a lower pressure section of the turbine, and then back to the reactor core. This system is claimed to provide inherent self-control over a wide range of power output, varied simply by controlling the secondary steam control valves on the turbine.

The fuel would again be UO_2 but clad in Zircaloy-2, with a moderator-to-fuel volume ratio of 2·5 compared with only 1·12 in the BWR. The optimum fuel cost in the BWR would occur at 2·1 volume ratio, but 2·5 was chosen in order to provide an acceptably low void coefficient of reactivity, whilst still retaining a slightly undermoderated condition, in order to provide satisfactory stability and control characteristics. This relatively high moderator ratio gives a well-thermalized neutron spectrum, lending itself to normal cruciform control rods and calling for zirconium rather than stainless steel fuel cladding. The slightly lower steam pressure and temperature available to the turbine gives an efficiency of 31·2 compared to 34·5 in the PWR. The choice of feed pressure to the turbine is directly bound up with the reactor pressure vessel and coolant circulation system pressure, and therefore although pressures ranging from 800 to 1450 lb/in²g. and corresponding dry saturated temperatures of 518°F to 590°F were considered, it turned out that the economic optimum occurred at 950 lb/in²g. In other words, the bulkiness of the BWR core sets an economic restriction on the realizable steam outlet conditions.

It has been seen that the AEC consider that the BWR may well be the ultimate winner in the power-cost race provided nuclear super-heating can be developed. This development would depend on a new fuel and cladding technology and was not assumed feasible for the present design study. However, it is noteworthy that even the uranium oxide-zirconium technology is not yet fully beyond question, as revealed in a paper by C. N. Spalaris and H. E. Williamson of the General Electric Company who described results of irradiation tests of oxide fuel clad in Zircaloy-2 and stainless steel jackets. In tests in which a deliberate perforation of the Zircaloy cladding was made before the test, it appeared that zirconium oxide and hydride was formed around the site of the perforation resulting in distortion and swelling. Since Zircaloy-2 is known to have good corrosion resistance in water at 700°F and the can temperature in these tests was only around 600°F, some additional mechanism must have been operative. The authors suggested that this could either be due to the intermittent ingress of water deep into the interior of the fuel pellets via the radial and circumferential fissures which form in oxide after operation under reactor conditions, resulting in the repeated impingement of high temperature steam upon the zirconium, or alternatively to an unknown irradiation effect.

These authors also demonstrated that the amount of cracking and the formation of a central void, probably following upon melting and re-crystallization at the fuel element centre, is a function of the pellet-can clearance: voids were hardly detectable at a diametral clearance of 0·003, but occurred up to 0·040 in. dia. for larger diametral clearances up to 0·016 in. even following quite small irradiation doses. The objection to melting conditions in the centre of the elements is that under these conditions considerable quantities of fission gases are released with consequent pressure rise in the fuel can. These tests were all carried out at high heat fluxes of order 120 watt/cm², and doses of up to 3500 MWd/T have been achieved. All of the tests were upon 0·5 in. dia. pellets of 93-97% theoretical density, 2·02 oxygen/uranium ratio, 2·3% U-235, sintered at 1600°C. Most of the tests were in Zircaloy cans of 0·030 in. thickness with helium filling. One of the tests referred to stainless steel cans.

In the BWR design study, it is planned to employ solid-cylinder type fuel elements as in the tests reported above, but only 0·40 to 0·45 in. dia. These would be made up from sintered and ground pellets inserted into accurate Zircaloy tubes with welded end-closures, several such tubes joined end-to-end by means of spacer plates to form a fuel rod, several rods forming a fuel element assembly. The next objective would be to develop single-length fuel rods, if possible fabricated by the swaging technique. In the BWR design presented fuel-adjustment operations would be more frequent than in the zoned PWR, 20% of the fuel being replaced on each occasion with an average burnup of 10,000 MWd/T. It should be noted in connexion with the burnup figures given in these studies that the claimed power costs are based on a number of different assumed attainable burnup values, but in the AEC evaluations the costs have been re-assessed on a basis of 13,000 MWd/T for all schemes.

ORGANIC-COOLED REACTOR

The third power reactor study was dealt with in two papers, one by J. D. Plawchan of Bechtel Corporation

and R. F. Wilson of Atomics International, the other by J. Brunings, B. Hoffman and R. F. Wilson, all of Atomics International. There were several other papers dealing with specialized aspects of organic cooled systems which will be referred to below. Before beginning the AEC study, a preliminary investigation was made to determine which was the best moderator to use with the organic liquid coolant used either with simple forced convection or with moderate boiling conditions (Figure 2). Seven possible moderators were considered and of these Be and BeO were immediately ruled out on grounds of excessive capital cost charges, despite the resulting compact core, arising from their current market value of $100/lb for Be and $50/lb for BeO. Light water as moderator would have the advantage of greatly reducing the quantity of organic within the reactor core and exposed to radiation damage, perhaps reducing the make-up rate to a quarter or less than that of the organic moderated reactor. However, there is the considerable practical difficulty of either having the water rather hot and hence at very high pressure, thus losing one of the major advantages of the organic coolant, or alternatively having the water quite cool and therefore requiring efficient heat insulation between the coolant tubes and the moderator with consequent problems of cross-leakage of the two liquids, neutron absorption in insulation and neutron loss through streaming along interspaces. These problems have considerable uncertainties and would account for the large shaded area in the histogram.

Hydrogen moderation could also be considered if used in the form of zirconium hydride. This would give a compact core and a neutron economy much as the organic moderated, organic cooled reactor (OMCR), whilst much reducing the required organic make-up rate; but too little is known about the radiation stability of this material to enable a reliable design to be based upon it.

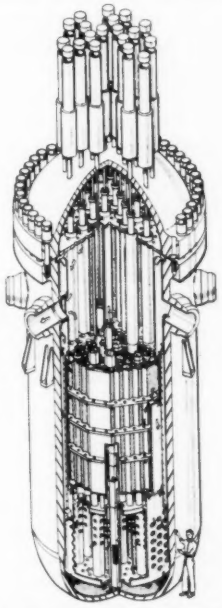
Even so there would appear to be a considerable advantage to be gained in an organic reactor if the moderator is other than organic in order to reduce the organic damage rate, and Atomics International looked closely at the remaining four alternative schemes. The heavy water moderated scheme, such as is being developed by the Canadian General Electric Co. as an alternative to the pressurized heavy water cooled CANDU reactor, was rejected on the grounds that the costs of interest charges on the D_2O investment, of the D_2O losses and of heat loss ($\sim$ 7% of the total heat production) at low temperature to the moderator offset the low fuel and organic make-up costs. Nevertheless it is the only organic scheme which could offer long burnup of natural uranium.

The graphite moderated version offers similar advantages of operating on natural or near-natural uranium but with lower reactivity life in the case of natural fuel, though it was considered to lose on the large size and the resultant high capital charges. The design studied made use of process tube liners to separate the organic from the graphite and presumably would require a separate gas coolant circuit, probably CO_2, to cool the graphite. There is also the possibility of nuclear superheating in other process tubes. Although graphite heat could in principle be taken out at a temperature as high or higher than that of the organic and recovered as mechanical power, it probably would not prove economic, and it is therefore of interest to know whether this system could be worked with the organic in direct contact with the graphite, eliminating the cost and complication of process tubes and auxiliary cooling circuits, improving neutron economy and making available the moderator heat for conversion to mechanical power.

In answer to questions at the meeting the author could make no comment on this possibility; clearly there are important questions regarding chemical compatibility under radiation conditions which would need experimental investigation. The elimination of the process tubes and auxiliaries might well bring the graphite reactor costs below those of the organic moderated system. In this connexion it is worth noting that, although probably heavier on capital charges, the graphite moderated system gains in avoiding the degree of fuel enrichment required by the OMCR.

OMCR the most economic

For the reason that all these practical difficulties each make their contribution to the cost of power, the simplest and almost the most compact system, the OMCR (Organic Moderated and Cooled Reactor), turned out to be the most economic despite high make-up rate costs and the need for substantially enriched fuel. In the design submitted to the AEC, nucleate boiling is assumed permissible in the core and finned cans of SAP (sintered aluminium powder) are assumed to be a practicable proposition. These are the two major development assumptions of the design, upon which its high performance claims are critically dependent. Both technologies require a good deal of further investigation and demonstration before they can be acceptable as 'guaranteeable' under the ground-rules of the AEC contract, and to this extent the OMR study is not strictly comparable with the PWR and BWR systems.



The 248 MWe advanced PWR, the most developed of the four design studies, operates at 600°F and has the high thermal efficiency of 34·5%. In the two-zone core fuel clusters of UO_2 pellets clad in s.s. are arranged in a right circular cylinder, diameter 98·2 in. (Fig 1)

The OMCR design employs 46,500 kg of 2·1% enriched UO_2 pellets clad in extruded tubes, helically-finned, of SAP (or APM = extruded aluminium powder metal). This material contains 7% of aluminium oxide and is claimed to possess better creep-rupture properties at high temperatures than aluminium alloys. A two region core is specified giving an attainable average burnup of 15,000

MWd/T at a specific power of 20 kW/kgU. The coolant-moderator is Santowax R, permitting a bulk outlet coolant temperature of 675°F. The maximum can surface temperature is 850°F with a heat flux of about 40 watts/cm²: nucleate boiling is permitted at hot spots in the core, and the burnout factor is 2·0, the coolant system pressure being 50 lb/in² abs.

Heat transfer and decomposition

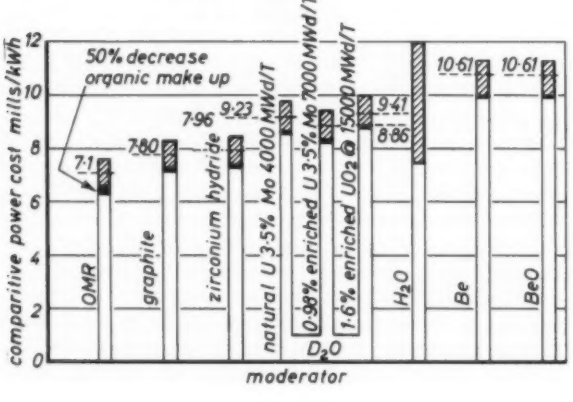
There were several other papers of direct relevance to the organic coolant problem, including a paper on heat transfer by D. A. Huber and J. L. Kortenhoeven of Atomics International and a paper on the decomposition of organics by R. H. J. Gercke, also of Atomics International. The heat transfer paper referred particularly to the effects of surface films formed by decomposition of the organic, that is the fouling effect, using pre-irradiated OMRE coolant containing 30% high boiler compounds of volatility less than that of para-terphenyl. Under non-boiling conditions no detectable fouling was observed up to 850°F for 5 ft/s flow rate and none up to 950°F for 14 ft/s.

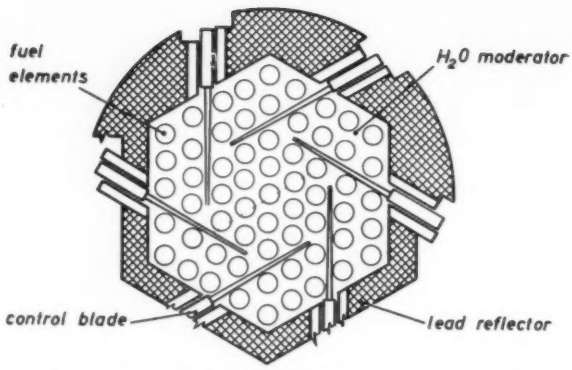
As already mentioned, allowing nucleate boiling in the core enables larger heat transfer rates to be attained and the advanced study reported above depends upon this feature. The second part of the reported heat transfer tests concerned the investigation of fouling under nucleate boiling conditions, and preliminary results indicated that a gradual decrease with time of heat transfer coefficient occurred in tests of up to 500 hours. One test of 2000 hours showed that it attained an equilibrium value.

There are still discrepancies between the rates of decomposition caused by radiation as investigated by various laboratories, and also concerning whether damage is simply proportional to energy absorption or whether fast neutrons are more damaging per unit of energy absorbed than other radiations. R. H. J. Gercke reported that the rate of damage decreases with high boiler residue (HBR) content, and that for 30% of HBR the number of molecules reacting per 100 eV of energy absorption is 0·15, as measured in OMRE, which may be compared with 0·18 measured in MTR loop experiments. Based on the best available data the author concludes that the coolant makeup rate at reactor operating temperatures and fluxes would be 27 pounds per MWd (thermal), leading to a charge of 0·62 mill/kWh for a 300 MWe station.

Aluminium powder metal (APM) (known in Europe as SAP) suitable for use in the organic-type reactors were

Comparative power costs of organic cooled reactors using seven possible moderators (Fig. 2)





Designed for transportation by trailer or aircraft, the ML-1 weighs only 15 tons dry. The 450 MWe reactor is nitrogen cooled, water moderated, with aluminium insulated tubes (Fig. 3)

discussed by W. H. Friske also of AI. Preliminary results appear promising: tensile tests of APM alloy M-257 (6 to 8% Al_2O_3) at 800 and 900°F confirm the improved high temperature strength (UTS and yield) of APM as compared to wrought aluminium alloys, and notch sensitivity both hot and cold is satisfactory. Creep tests are not yet sufficiently complete for conclusions to be drawn. This material is said to be suited for cladding UO_2 fuel elements.

Nevertheless, for the immediate future for use in the Piqua 11 MW power reactor reliance is being placed upon uranium metal alloy (U-3·5% Mo-0·1% Al) metallurgically bonded to an extruded aluminium finned can by evacuation and hot pressing at 8000 lb/in², 1000°F, for 10 minutes. The actual bond is effected with a nickel coating and intermetallic compounds formed during the hot pressing, giving the materials sequence Al-Al_3Ni-Al_2Ni_3-Ni-UNi-UMoAl. This is reported by C. W. Wheelock of AI, who deals also with the consequences of some accidental plugging of fuel passages with *in*organic impurities not adequately filtered from the system which led in this case to the melting of some 40 square inches of cladding, but to only slight resultant contamination of the coolant circuit.

SODIUM COOLANT PROBLEMS

The safety problem of running liquid sodium through a heavy water moderated core, coupled with the fact that the presence of sufficient sodium for the heat transfer requirements probably makes operational criticality with natural uranium unattainable, together sway the balance to indicate that the sodium cooled heavy water moderated reactor scheme is not really feasible at the present time.

Similar difficulties apply also to the sodium graphite reactor except that the water-sodium hazard in the core is avoided and the problem of isolating cool heavy water from hot sodium is replaced by that of keeping the sodium out of the graphite porosities. In the SRE this was achieved by zirconium cladding the graphite moderator blocks, but in the Hallam power reactor design stainless steel will be used for this purpose. This makes the neutron economy of the Hallam 254 MWt, 3%enriched, station worse than a PWR: it has a cold clean conversion factor of 0·5 compared with 0·529 for the Yankee 392 MWt, 3·4% enriched PWR of similar category of heat output.

Apart from the fundamental difficulties of radioactivity, thermal neutron absorption and the need for special construction and materials for external components, there remain considerable difficulties in designing suitable fuel

materials and cladding, as reported by both C. F. Bullinger in a paper on SGRs and by E. D. Jordan on the sodium heavy water proposals. Summing up the various coolant-cladding-fuel combinations considered as promising in these and other papers we arrive at the position shown in the following table:—

COOLANT	FUEL	CAN	COOLANT OUTLET TEMP. °F	STEAM TEMP. °F
Water	UO_2	Zr	620	550
	UO_2	s.s.	620	550
Organic	U-Mo	Al	575	550
	UO_2	SAP	675	650
Sodium	UO_2	Zr	1025	825
	U-Zr	Zr	1025	825
	UO_2	Nb	1150	1000
	UO_2	s.s.	1150	1000
	UC	Nb	1150	1000
Helium	UO_2	s.s.	1060	860
	UO_2-C	None	2400	>1000

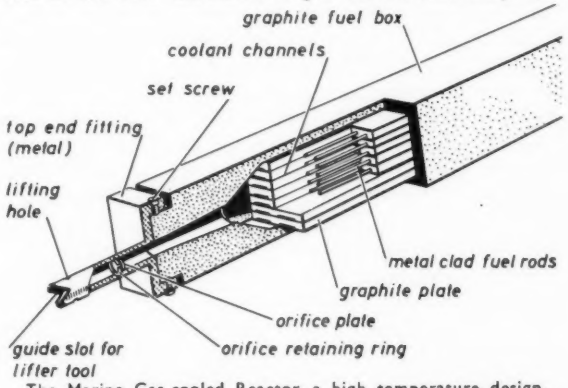
HEAVY WATER SYSTEM

Returning to the four AEC design studies, the fourth of these was the heavy water moderated system, reported on by W. A. Chittenden of Sargent and Lundy and J. D. Hutton of Nuclear Development Corporation of America. The ground rules for this system were originally somewhat different from those of the first three, the main differences being the required ability to operate economically on natural uranium and that the design produced was for a 200 MWe rather than a 300 MWe plant. Although able to operate on natural uranium, it was acceptable that its optimum economy could be with enriched uranium. After examining many possible types the conclusion was reached that the boiling water, pressure tube, direct cycle reactor was the best choice for the study, both on account of excellent thermal performance and potential for future development to larger sizes. The 1 inch thick aluminium calandria vessel, 18·4 ft dia. by 20·7 ft high, is pierced by 287 aluminium calandria tubes on an 11·1 in equilateral triangular pitch and contains heavy water at 155°C. The pressure tubes passing through the calandria tubes are of Zircaloy-2, 4·97 in. dia., and contain fuel elements in the form of 37-rod clusters of 0·552 in. diameter UO_2 clad in Zr-2: there is air between the pressure tubes and the calandria tubes to serve as a heat insulator. Steam leaves the steam-drum separator system at 750 lb/in²g., dry saturated (510°F). With 4-zone outward radial shift of fuel and axial inversion of fuel elements some 7500 MWd/T might be achieved with natural uranium, or 10,000 MWd/T with slightly enriched fuel at a fuel cost saving of 0·1 mill/kWh.

GAS-COOLED SYSTEMS

These fall essentially into three categories at the present stage of development, dominated by the fuel element technology which includes metal clad (especially stainless steel) systems, the impermeable graphite clad systems and the unclad systems, although there are some proposals for hybrids. Although much attention is being turned on to these systems in the United States, relatively few papers were presented on these topics at the meeting. A paper by L. L. Kintner of Allis-Chalmers Manufacturing Company discussed the thermal design of the helium-cooled graphite-moderated, 84·3 MWt Experimental Gas-cooled Reactor. This design achieves a specific power of 7·6 kW/kg of uranium at an average heat flux of 20 W/cm² with a coolant outlet temperature of 1050°F. The stainless-steel clad UO_2 fuel elements are arranged in 7-rod clusters on an eight-inch square pitch in 216 channels, each fuel channel being 3 in. dia., the elements 0·75 in. o.d. with 0·020 in. thick cans. The fuel channels are actually formed by graphite sleeves of 5 in. o.d. by 3 in i.d. which serve to separate the fuel coolant and moderator coolant gas streams: this is in order to keep the main volume of the fixed part of the moderator at over 1000°F for the self-annealing of strain energy, since the coolant enters the fuel channels at the relatively low temperature of 510°F. Heat transfer details for this system were also given in a paper by C. L. Beaudoin and R. N. Higgins, of A-C.

Another gas-cooled reactor now being developed by the Atomic Energy Commission for the US Army and producing quite high coolant outlet temperature is the ML-1 mobile nuclear power plant (Figure 3). This reactor uses UO_2 fuel with 'metallic' cladding and nitrogen coolant which leaves the reactor at 1200°F to produce 450 kWe by means of a gas turbine, the inlet pressure to which would be about 200 lb/in²g. and which would operate at about 16% thermal efficiency. The reactor is to be as compact as practicable to make air transport feasible, and to achieve this it is water moderated (with insulated process tubes), employs a lead reflector and has a disposition of fuel in the core calculated to provide an essentially uniform radial power distribution giving a ratio of (peak element power)/(average element power) of 1·11, compared to 1·47 for a uniform spacing. This power distribution problem was the main topic in a paper by F. J. Thomas and S. J. Perkins of Aerojet. If the present core design is as originally planned for the GCRE (ML-1 in the new nomenclature), the core size is 2 ft dia. by 2·5 ft in length with 1·875 in. dia. process tubes. The present design will weigh 15 tons dry and will be provided with partial shielding only for operation from a cab 500 ft distant.

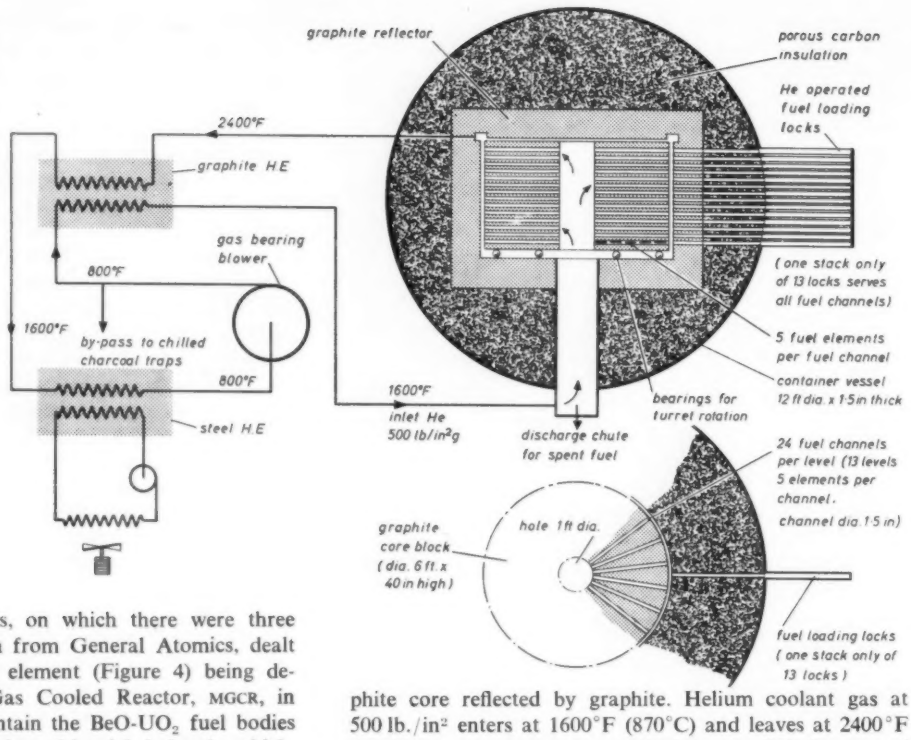


The Marine Gas-cooled Reactor, a high temperature design, has semi-homogeneous fuel elements containing BeO-UO_2 fuel in a thin nickel sheath inserted in graphite plates (Fig. 4)

Another portable power reactor for military purposes was described by F. Hittman of the Martin Company. This reactor has a core size similar to the ML-1 just described but in this case heat removal is by means of pressurized water and the power output is 1000 kWe. As in the original army power reactor, the APPR, the fuel elements are of a UO_2-stainless steel cermet clad in stainless steel. This reactor has also been designed to be transportable by air, the whole plant being able to be assembled into a number of packages each not exceeding 30,000 lb in weight, 30 ft in length and 8 ft 8 in. square in cross-section.

High temperature designs

The next phase in gas-cooled reactor technology will be the HTR (High Temperature Reactor) type with semi-


graphite reflector
porous carbon insulation
He operated fuel loading locks
2400°F
graphite H.E
gas bearing blower
800°F
1600°F
by-pass to chilled charcoal traps
800°F
steel H.E
1600°F
inlet He 500 lb/in²g
discharge chute for spent fuel
bearings for turret rotation
(one stack only of 13 locks serves all fuel channels)
5 fuel elements per fuel channel
container vessel 12 ft dia. x 1·5 in thick
24 fuel channels per level (13 levels 5 elements per channel.
channel dia 1·5 in)
graphite core block (dia. 6 ft. x 40 in high)
hole 1 ft dia.
fuel loading locks (one stack only of 13 locks)

Scheduled to start construction in 1960, the Los Alamos 3 MWt turret reactor will have the very high coolant exit temperature of 2400°F. The cylindrical core rotates within the spherical vessel and can be moved on load to bring each row of fuel channels in alignment with the bank of charging rams (Fig. 5)

homogeneous fuel elements, on which there were three papers. Two of these, both from General Atomics, dealt with a 'compromise' fuel element (Figure 4) being developed for the Marine Gas Cooled Reactor, MGCR, in which it is proposed to contain the BeO-UO_2 fuel bodies of between $\frac{1}{4}$ and $\frac{1}{2}$ in. dia. in a thin nickel sheath, which, unsupported, would be too weak in the absence of a coolant pressure to sustain the fission gas pressure within. However, by inserting these in close-fitting holes in a graphite plate sufficient strength is provided by the graphite (1100 lb/in² tensile stress for rupture) to prevent can rupture following loss of coolant pressure, and fuel-to-gas heat transfer can take place over a fairly large surface area. The main difficulty with this system concerns carburization of the cladding at the high can temperature of 1700°F and above: for this purpose only 'A' nickel appears to be chemically and metallurgically suitable.

The other approach to the cladding problem in HTR designs is to develop impermeable graphite, and recent developments and testing methods are reported in a paper by E. E. Anderson, R. D. Burnette and L. R. Zumwalt, all of General Atomics. Different methods of rendering graphite impermeable are tested by means of measuring the diffusion of I-131 and Xe-133 through the graphite at 1200°C, these fission products being produced by irradiating 1 gram of uranium carbide fuel within the test capsules at 7×10^{11} n/cm²/s for 4 hours. An 0·01 in. thick coating of SiC-Si at 1200°C appears to have a Xe-133 permeation constant some 100 times smaller than that for helium in quartz glass at room temperature: helium permeation at room temperature is similar to that in quartz glass.

Finally, great interest was shown at the meeting in the Los Alamos Turret reactor, reported upon by R. P. Hammond and others. In this concept (Figure 5), no attempt is made to keep the fission products within the fuel elements, and the whole activity is allowed to leak at will into the gas coolant stream. Fuel elements are ordinary graphite tubes, 6 inches long, 1 in. o.d., $\frac{1}{2}$ in. i.d., which are impregnated with U-235 by dipping into a solution of enriched uranium nitrate absorbing about 4·5 g U-235 per element. The total fuel charge is 7 kg in a 6 ft. dia. graphite core reflected by graphite. Helium coolant gas at 500 lb./in² enters at 1600°F (870°C) and leaves at 2400°F (1330°C), a temperature specified by the US Bureau of Mines for a coal gasification process, although at present the heat is to be rejected via a steel air-cooler. To enable this to be done and also to limit the gas temperature to be handled by the gas-bearing circulator, the outlet gas is first passed through a graphite regenerative heat exchanger. Part of the flow is by-passed through a purification system which removes all fission products every five minutes.

Numerous papers dealing with circulating liquid fuel systems were given but the present AEC opinion, as expressed by J. E. Draley of ANL, appears to be that all these systems require a great deal of development work before they can be considered feasible for economic power schemes. Despite the great amount of work already done upon the HAR (Homogeneous Aqueous) and the LMFR (Liquid Metal Fuel) systems, the present opinion is that in fact the molten salt solution systems (MSR) showed more promise for easy development. This is mainly on account of the fact that both the HAR and the LMFR require a slurry system as an essential component and great difficulty has been encountered in the development of practicable slurry handling core or blanket systems. In addition both these systems suffer from considerable corrosion difficulties which look like being very difficult to circumvent, and it seems likely that the corrosion situation will be easier with the MSR. Lastly, maintenance difficulties and the complex auxiliary systems are thought to constitute major problems and cost factors in all plants of this class.

However, all three of these liquid fuel systems are considered to be capable of development into 'hold own' breeders which would operate on the thorium U-233 cycle requiring refuelling with natural thorium only. Each type of reactor would require ten years of concentrated development work and over one hundred million dollars of development expenditure to bring it into the practicable category.

STUDENTS' NOTEBOOK

GROUNDWORK—Instruments

What is the difference between an ionization chamber, a proportional counter, and a geiger counter?

Stripped of all details of design, they take basically the same form—a gas filled chamber containing two electrodes across which a voltage difference is maintained. (See Fig. 1). When radiation in the form of charged particles passes through the gas it ionizes some of the molecules, i.e., removes an electron; the resulting molecules-minus-one-electron, called positive ions, and the electrons, are then attracted to the electrodes of opposite polarity so that a current flows through the external circuit.

At low voltages many of the positive ions and electrons will recombine before they can reach the electrodes. As the voltage is raised, however, causing them to move faster, more will be collected before they can recombine, until at a certain voltage level (B. Fig. 2) all the positive ions and electrons formed are collected. Raising the voltage now makes no difference to the current: the detector is in the saturation region (BC) and is working as an *ionization chamber.*

The number of positive ions and electrons formed by a particle terminating inside a chamber equals the kinetic

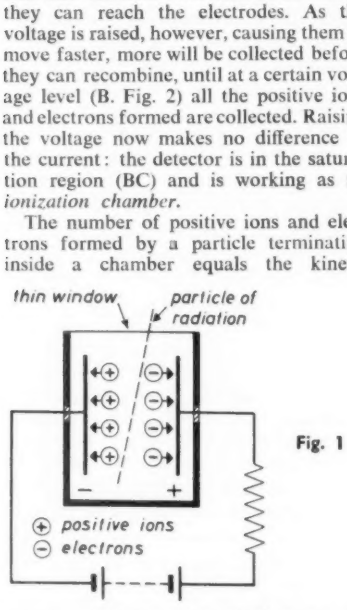


Fig. 1

energy of the particle divided by the energy required to remove an electron from a molecule in the gas; the current in the external circuit, which is the total charge arriving at one electrode per sec, is therefore a direct measure of the rate of entry of the ionizing particles and hence of the intensity of the radiation.

If the voltage is raised above (C) a new phenomenon occurs: some of the electrons will now move so fast that they themselves ionize other molecules by collision; secondary electrons so formed can, in turn, produce further ionization and so on. The total charge arriving at an electrode can now be thousands of times larger than the charge on the positive ions and electrons first produced by the radiation, though still proportional to it, and the chamber is working as a *proportional counter* (CD).

At still higher voltages (above E) the proportionality ceases and the size of the current becomes independent of the original amount of radiation—it is just a discharge triggered by the initial event. This is now a *geiger counter.*

Besides charged particles (protons, alpha particles and electrons) an ionization detector can be used for gamma radiation, which also causes ionization (sometimes

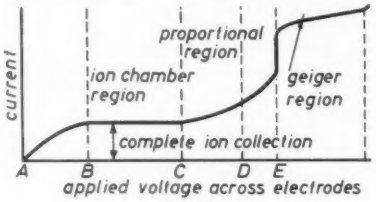


Fig. 2

accompanied by X-rays). For neutrons, which do not produce ionization directly, use can be made of a nuclear reaction by introducing, say, boron into the chamber. The resulting alpha particles will carry out the necessary ionization. Alternatively, uranium-235 can be used, and in this case ionization will be caused by the fission fragments.

What is the difference between a Rad, a Rem and a Roentgen?

The Roentgen is the unit of radiation, the Rad that of absorbed dose; the former is that amount of radiation which will produce enough ionization in one cc of air (at STP) to amount to one electrostatic unit of charge, while a Rad is that amount of absorbed radiation which equals 100 ergs per gram of irradiated material. The Rem is a measure of dose:—the quantity of ionizing radiations which, when absorbed by the human body, produces a biological effect identical to that produced in the same tissue by one Rad of X-radiation.

BOOKLIST—Nuclear physics

Nuclear Physics. I. Kaplan. Addison Wesley. 1955. Good general introduction (long 609 pages). No previous knowledge of atomic or nuclear physics assumed; questions included.

Elementary Nuclear Physics: W. K. Mansfield. Temple Press. 1958. Short elementary account (60 pages) of atomic and nuclear physics including the detection of nuclear radiation; specially for budding nuclear engineers.

Source Book on Atomic Energy. S. Glasstone—Van Nostrand. 2nd Edn. 1958. No previous knowledge needed; excellent and readable account of atomic and nuclear physics and atomic energy.

Radioactivity and Nuclear Physics: J. M. Cork. Van Nostrand. (2nd Edn. 1950). Fairly elementary; mainly descriptive; questions included.

Applied Nuclear Physics. E. C. Pollard and W. L. Davidson. Wiley (Chapman & Hall). 1951. (2nd Edn.) Particularly good on practical applications; small section on the application of fission.

The Atomic Nucleus. R. D. Evans. McGraw-Hill. Already a classic; comprehensive and detailed account but good on practical aspects; not for beginners.

Introductory Nuclear Physics. D. Halliday. Wiley. 1950. Good knowledge of atomic physics assumed, especially for parts in small print; large sections on interaction of charged particles with matter and the detection of charged particles. Questions included.

NEWSBRIEFS

- International School of Nuclear Science and Engineering at Argonne becomes the International Institute of Nuclear Science and Engineering with effect from Feb. 3: curriculum will be broader, more advanced.
- West Instrument Ltd. Recent course on function of the saturable core reactor had an attendance of fifty.
- Release and Use of Atomic Energy. The course of six lectures for juveniles at the Royal Institution will be given by Dr. T. D. Allibone, starting Dec. 29.
- Effect of Technological Progress on Education. This new bibliography published by the Institution of Production Engineers covers the development of technical education from 1945 to '57.
- Fuel Element Technology. A course of ten weekly lectures by AEA specialists has been arranged at Imperial College, starting Feb. 11.

UK COURSES—Reactors

Diploma and degree courses for graduates

University of Birmingham: M.Sc. 1 year. Oct 1960, £81. Reactor physics and technology, also radioactivity. Apparatus includes 60 in. cyclotron.

Glasgow, Royal Coll. Science and Tech.: Diploma. 1 year. Oct 1960, £55. Nuclear power engineering (part of one-year course on power engineering).

Imperial College, London: Diploma. 1 year. Oct 1960, £124. Nuclear power. Apparatus includes sub-critical assembly and comprehensive analogue computer.

Queen Mary College, London: Diploma 1 year. Oct 1960, £90. Nuclear engineering. Experimental work on a sub-critical assembly and a research reactor.

Manchester University: Diploma. 1 year. Oct 1960, £60. Nuclear engineering.

Short courses for graduates

Harwell Reactor School: 16 weeks. Jan, Aug 1960. £250. Reactor physics and reactor engineering. This famous course includes use of extensive apparatus, including some Harwell research reactors. The first six weeks forms a general introduction, and is given at a Technical College (Birmingham, Bradford or Salford).

Calder Operation School: 5 weeks. Feb 1960 (UK students). Jan 1960 (Overseas students). £125. Reactor operation.

Manchester University: 6–8 weeks. May 1960. £45. Nuclear engineering. Apparatus includes graphite and hydrogenous stacks, cooling rigs and analogue computer.

Birmingham College of Technology: 6 weeks, Jan, Aug 1960. £60. First part of Harwell course, but can be taken independently.
6–8 weeks (3 per year), £60. Nuclear power technology.

Bradford Institute of Technology: 6 weeks. Jan, Aug 1960. £60. First part of Harwell course, but can be taken independently.
6 weeks. Frequently uncertain. £30. Nuclear reactor technology.

Salford Royal Technical College: 6 weeks. Jan, Aug 1960. £60. First part of Harwell course, but can be taken independently.
8 weeks. May 1960, £60. Reactor physics; similar to above, but not tied to Harwell.

Next month—*courses in Electronics and Instrumentation.*

Concluding an article started in October, Hall shows how plant for handling fissionable materials can be designed and operated to be inherently safe

Criticality problems in chemical plant design

by G. R. HALL, D.Sc., F.R.I.C.
Reader in Nuclear Technology, Chemical Engineering Department, Imperial College, London

THE BASIC FACTORS which may lead to a criticality hazard in a chemical system were discussed in the first part of this article. It was pointed out that, in most nuclear fuel processing plants at present, criticality control is primarily achieved by administration. Thus the mass, volume or concentration of fissionable material at any part of the plant is maintained within safe limits by analytical methods but there is always the chance that the human error may lead to an accident. This applies to plant handling enriched uranium, uranium-233 or plutonium. It should be borne in mind that it is possible to obtain a critical assembly with very low enrichments of uranium; thus the lower limit of enrichment below which criticality is impossible is at about 1% uranium-235, but varies with the type of system.

Geometrically safe equipment

It has been shown that vessels of certain dimensions (e.g. the 5·0 in. diameter infinitely long cylinder for plutonium) are always safe. From such data has developed the concept of the geometrically safe plant such as the 'eversafe' fuel dissolver unit and slab mixer-settler illustrated in Part I. A great deal of work has been carried out both in the United States and the United Kingdom to design geometrically safe mixer-settlers. It is relatively simple to specify dimensions which are safe but very difficult to obtain settlers which, whilst of safe geometry, are also able to cope with sufficiently large flow rates.

These remarks apply also to the design of dissolver units, where the achievement of sufficiently high flow rates also presents problems. The 4 in. diameter dissolver illustrated in Figure 1 of Part I can dissolve uranium, without residue, by continuous dissolution. The acid is added continuously and the metal builds up in the dissolver until equilibrium is achieved between the rate of addition and the rate of solution. The dissolver liquor achieves a constant composition in which the variation of concentration is about ±5%. The dissolver liquor is removed from the unit through the thermal syphon circulating arm. The latter also ensures rapid circulation and this prevents foaming, a problem to be expected in narrow bore vessels.

OUTLINE

Following the discussion of basic factors in criticality control, in the first instalment, Hall shows how they affect the design of geometrically safe equipment and plant. Experiments at Dounreay on the influence of materials used in processing and some dangers in typical processes are described. He reports on the accident at Oak Ridge in 1958 and outlines the essentials of nuclear safety organization.

A centrifuge has been developed at Dounreay for removing traces of solids from active feed streams (*1,7*). These solids are of very small size and quantity (1–40 ppm) but they can lead to trouble by collecting at solvent-aqueous interfaces in the solvent extraction equipment. This modified Sharples supercentrifuge is of eversafe geometry and may be operated remotely from behind the plant shielding.

An eversafe evaporator (*1*) is illustrated in Figure 3. This is used for the concentration of pure uranium and plutonium aqueous nitrate solution streams. It operates on continuous feed and automatic intermittent take-off of product is provided for. Radio-frequency induction heating is used and in order to prevent contamination by corrosion products the apparatus is made in glass. The fissionable solution is circulated rapidly through a cyclone where vapour and liquid are separated and the liquid is recycled. A magnetic valve, which is operated by a signal from a gamma-absorptiometer, ensures that the product is taken off at a chosen predetermined concentration. This is a most interesting equipment and is used at a point in the processing plant where criticality hazards might be expected to be greatest, i.e. where the concentration of fissionable solutions becomes high.

Many other types of critically safe equipment have been described in the literature but only two further examples will be referred to here. The first is the use of fluidized-bed reactors in uranium processing. These are now used on a large scale in processing natural uranium, but where enriched uranium is handled it is necessary to consider critically safe reactors. Thus at Oak Ridge 5 in. diameter reactors have been developed for batch-processing of enriched uranium; these are used in the hydrofluorination of enriched uranium oxides (*8*).

The second example is the use of carefully designed ion exchange columns for the processing of uranium and plutonium. In general ion exchange processes have not found great favour for large-scale fuel processing because of the difficulty of ensuring adequate flow rates and also the cost of replacing resins which have become

general a saturated plutonium band 6–12 in. wide is desirable for good plutonium elution characteristics and Bruce considers such variables in relation to nuclear safety. Whilst no hazard is foreseen in handling plutonium nitrate solutions absorbed on the resin in a column 7 in. in diameter, it is advisable to ensure the columns are separated by 2 ft, centre of column to centre of column, and similar distances from other vessels containing plutonium.

Table 6 illustrates the data used by Bruce in considering ion exchange processes. It should be appreciated that this data refers to a particular column, as specified, and hence the critical dimensions are not the same as those given in Table 2 of Part I, where infinitely long cylinders are considered surrounded by an infinite water reflector.

Systems of complex geometry

For most of the equipment which has been discussed so far it has not been difficult to deduce safe dimensions because each equipment has been based on a single slab or cylinder. There are, however, many vessels and pipe systems used in a chemical plant which cannot be compared to such simple shapes. There are various ways of dealing with this problem:

1. It may be possible to compare a particular system with another equipment which is already known to be safe. Thus a bundle of parallel pipes close together may be considered safe because they may take up no more space than a concentric safe cylinder. Similarly a flat array of pipes may be compared to a safe slab. There are many pipe systems in a chemical plant which may be examined in this way, and it should be emphasized that the plant designer can reduce the plant criticality hazard by applying such considerations at the early design stage.

2. A considerable amount of nuclear data has been developed over the last few years and it is therefore sometimes possible for the physicist to calculate whether a particular equipment is safe or not. Such calculations usually depend on a consideration of a simple model which approximates in its features to the equipment in question but which is expected to be less safe.

3. The only way of deciding whether many complex shapes are safe is to carry out a test run under operating conditions and using fissionable materials. Such experiments are extremely costly to perform and the information obtained is often only applicable to the equipment under test. Such testing is usually carried out in isolated and specially equipped laboratories and in the United Kingdom these are situated at Dounreay.

TABLE 6. *Critically safe plutonium systems relevant to ion exchange processes*

Shape of vessels	right cylinder
Height of vessels	35 and 26·5 cm
Diameter of vessels	17·8 cm
Total volume of vessels	8·72 and 6·54 litres
Material of construction	Pyrex glass pipe; walls $\frac{1}{4}$–$\frac{3}{8}$ in. thick
Height of plutonium band	8·8 cm
Volume of plutonium	2180 ml
Concentration of plutonium	165–180 g/l
Total amount of plutonium	400 ± 40 g
Material outside vessels	air
Material inside vessels	a. $Pu(NO_3)_3$
	b. Dowex — 50 cation — exchange resin
Composition of resin	c. 0·3–6·0 M HNO_3 52%C, 17·5%S, 26·2%O, 4·3%H

Criticality experiments at Dounreay

Work at the Dounreay laboratories (*10*) has been particularly concerned with the investigation of systems whose nuclear safety is uncertain not so much because of geometrical features, but because of the properties of the constituent materials, including materials used to reduce the criticality hazard as well as those that augment it. Such materials may be solvents, lubricating oils used in vacuum pumps, break-down products such as partially fluorinated hydrocarbons, etc. All these materials would be expected to have differing moderating properties and hence could upset the critical data for a particular unit in a plant. Of the other topics being investigated at Dounreay, one—a study of anti-criticality poisons — is of particular relevance to the present discussion.

Mention has been made of the use of substances of high neutron cross-section such as boron or cadmium to decrease the possibility of a criticality hazard in chemical plant. These may take the form of fixed 'control' rods or may be dissolved or dispersed in a homogeneous system. Boro-silicate glass powder or rings, or ceramic pellets containing a suitable absorber, have been investigated using aluminium thimble tubes (containing the absorber) in an apparatus of the sort shown in Figure 4. This apparatus also illustrates the use of cadmium to control or shutdown a fissionable system. Thus a cadmium cylinder, which can surround the cylindrical core of fissionable solution, can be dropped into the tank. Boron- and cadmium-containing materials are also often used to surround the storage vessels which are used for fissionable materials.

An interesting application of an absorber in chemical plant is the incorporation of an insoluble boron compound, such as boron-silicate glass, into a column packing. It is essential to ensure that leaching out of the boron cannot occur.

The use of boron as a dispersed homogeneous poison in plant process streams has been suggested but at the present time it is not used in any large-scale process. Its use would be expected to lead to considerable relaxation in critical parameters but would also lead to added process problems. Thus the fuel processing plant has as its primary aim the extreme purification of the fissionable material, for example, the removal and purification of plutonium produced in irradiated uranium fuels. The presence of a strong neutron absorber, even in very small amounts, in the product plutonium might well make its subsequent use impossible. Even if the added boron can be completely removed, there are many problems connected with the stability of the boron in aqueous solution and at various parts of the chemical plant which require study. A complete assessment, involving criticality experiments, would also be needed on boron-containing solutions before this technique of using a dispersed homogeneous poison could be utilized in a fuel processing plant.

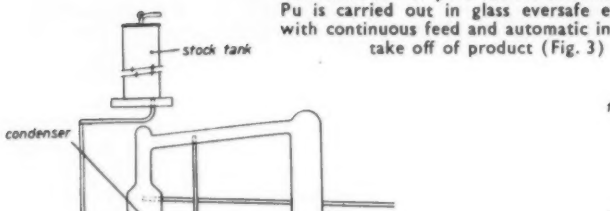
Dangers in typical processes

Aqueous fuel processing

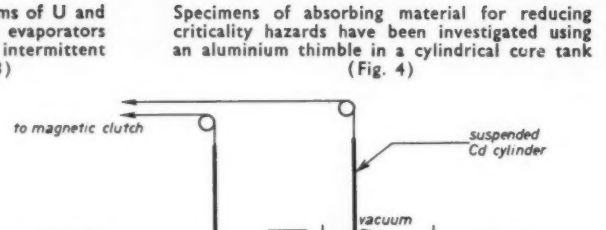
Much of the discussion has been devoted to the problems of handling aqueous fuels and attention has been drawn to some of the dangers to be expected and some of the precautions to be followed. In the case of highly enriched fuels, it is essential to use a plant of restricted size because of the low critical dimensions for aqueous fissionable materials. In fact it is highly desirable to ensure the plant is completely geometrically safe.

In the case of plant designed to process less highly enriched fuels, much existing plant does not incorporate geometrically safe equipment. An important hazard in such plant is the possibility of sludge depositing and a non-safe layer being formed. The fuel dissolving section is a likely place for this to occur and it is desirable to ensure that such sludge can only settle into a section of the plant where it forms a safe shape, or at

Concentration of pure nitrate streams of U and Pu is carried out in glass eversafe evaporators with continuous feed and automatic intermittent take off of product (Fig. 3)



Specimens of absorbing material for reducing criticality hazards have been investigated using an aluminium thimble in a cylindrical core tank (Fig. 4)



least is surrounded by a neutron absorbing material.

The dissolution stage and also other individual stages in the plant may be carried out batchwise. This makes the accounting of fissionable material easier but there is a danger that a double batch may inadvertently be added. For this reason, in batched steps it is often desirable to use safe quantities which are less than half the appropriate critical quantity.

Continuous processes are economically desirable but they do present administrative difficulties, especially if a hold-up occurs in the plant, because the associated analytical problems are greater. For this reason considerable efforts are being made to develop 'in-line' monitoring and analytical equipment.

Another possible place of danger in the processing plant is where the process streams separate. For example, in separating plutonium from natural uranium, or uranium-233 from thorium, the stream containing the fissionable stream may be well monitored but if the process should break-down and the fissionable material get into the uranium or thorium lines, then there may not be suitable safeguards and a criticality hazard may result. Again this is an eventuality that the plant designer should guard against and of which the plant operator must always be aware.

Metallurgical processes

In these the relevant critical data are much greater than those for aqueous processes (compare Table 1 and 4). This is one reason why such a great deal of work has been carried out on the development of high temperature processing methods in the USA. It is expected that, providing all moderators can be excluded from the plant, very much greater quantities of fissionable materials can be processed in a relatively small plant. On the other hand, such plant is very much more difficult to operate and there is already a great wealth of experience available in the management of aqueous processes.

Typical steps in a 'dry' process are the following: drying and ignition of precipitates; conversions to metal; melting, casting and sintering; rolling, pressing, milling and turning of the metal; storage. The principal hazard, in each case, after setting critical limits for each stage (which will depend on critical shapes and critical masses), is the sudden appearance of a moderating or reflecting substance. Flooding by water is an example—this could lead to a very hazardous situation. Interaction between adjacent parts of the plant is also an important factor and adequate use must be made of the spacing principle and the use of neutron absorbers.

These remarks are particularly relevant in considering the storage and transportation of metal products. Many containers which ensure that adjacent containers are well spaced from other containers have been described in the literature. McLendon (*4*) has described one (Figure 5) which is used for storing and transporting fissionable scrap materials.

Uranium hexafluoride processes

The handling of uranium hexafluoride presents many interesting problems. The pure gas has a density under most conditions which is sufficiently low to prevent the possibility of a criticality hazard. The gas is, however, very chemically reactive and is immediately converted to solid UO_2F_2 by moisture. Presence of water, therefore, apart from introducing a moderator also produces a denser uranium product which may lead to critically unsafe conditions. The solid fluoride can associate itself with varying quantities of hydrogen fluoride and water and this can lead to complications in attempting to assess critically safe conditions. The greatest danger would occur with water flooding when a solution of UO_2F_2 could result. McLendon et al (*11*) have discussed various aspects of enriched uranium processing including the problems of handling uranium hexafluoride.

The only other gaseous fissionable

substance which may be encountered in dangerous amounts is plutonium hexafluoride but no large-scale processes using it have yet been developed.

Criticality accident

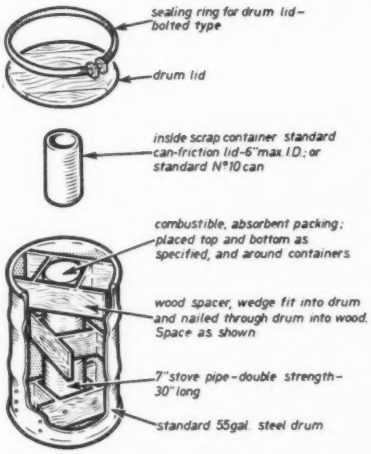
The only criticality accident, taking place in a chemical factory, which has been fully reported is that which occurred on June 16, 1958 at the Oak Ridge Y-12 plant (*12*). The report of the court of enquiry into this accident is a most valuable account and one which should be studied by all interested in nuclear chemical engineering.

The accident occurred in that part of the plant dealing with conversion of uranyl intrate to uranium tetrafluoride. For a number of years the process had been safely carried out using control by administrative methods and with conventional equipment. A new plant had been nearly completed for this part of the process and this plant had been designed on geometrically safe principles. In the interim period before complete shutdown of the old plant and complete commissioning of the new plant, sections of both plants were in use and the operation of the process was the responsibility of three supervisors.

At the time of the accident a monthly uranium inventory was being taken and this necessitated a stoppage of parts of the plant and washing out out of certain storage vessels. The whole plant was not stopped at the same time and so at any one time there was always uranium processing in progress.

It is not necessary here to outline in detail the way in which the accident occurred. In brief, prior to the accident, some enriched (90% uranium-235) uranium solution, containing about 50 g uranium per litre, flowed through a valved pipeline from the 'safe' plant into a storage vessel in the old plant. The latter vessel was of safe geometry. This transfer was not intended and was probably due to a leaking valve. In the old plant there were three of these 'safe' storage vessels connected by a valve pipeline and these were to be filled with water for leak testing. When a valve was opened to allow water from the storage vessels to flow into a 55 gallon drum, the uranium solution in the one tank and in the pipeline (connecting the old and new plant) first flowed into the drum. This was followed by water. The result was that a critical excursion took place in the drum and subsequent dilution finally produced a critically safe solution. It is believed the system was critical for about twenty minutes and in the initial neutron burst eight plant personnel received radiation doses ranging from 365 rads to 22·8 rads. It has been estimated that a total of about 10^{18} fissions occurred.

There were many contributory causes which led to this accident, but one which is immediately most apparent is the use of an unsafe 55 gallon drum in an enriched uranium processing plant. This was an unfortunate relic of the old plant where most of the criticality control had been enforced by administrative means. In a completely geometrically safe plant such a vessel would not have been permitted.


sealing ring for drum lid–bolted type
drum lid
inside scrap container standard can-friction lid-6"max.I.D.; or standard N°10 can
combustible, absorbent packing; placed top and bottom as specified, and around containers
wood spacer, wedge fit into drum and nailed through drum into wood. Space as shown
7" stove pipe–double strength–30" long
standard 55gal. steel drum

In this device for storing and transporting scrap fissionable materials, the container is held centrally in the drum by a wooden frame (Fig. 5)

A most interesting part of this report is the discussion of the measures taken after the accident, not only in the cleaning up of the plant, but also in the efforts made to assess the extent of the critical excursion and the radiation doses received by the personnel. The indium foils carried by process workers gave an immediate indication of which personnel had been exposed to neutrons but did not give reliable data on radiation doses. The sodium activity in the blood of the exposed personnel provided the best data on the individual radiation doses.

Nuclear safety organization

Attention has already been drawn to the necessity of criticality experts being brought in to assist in plant design at a very early stage. Their presence is important at the time a process is chosen, during the preparation of flow sheets and detailed planning of process equipment, and when the plant is tested and put into operation. This applies for plant relying primarily on either geometric or administrative control.

Training is of great importance especially when dealing with the process worker. He may have no special scientific training and yet he must be made aware of the danger to be expected from a criticality accident. He must know what factors can lead to the accident and he must be taught, or perhaps it would be better to say conditioned, to act very rapidly if an accident occurs. It is very difficult to get these ideas over, particularly when the precautions taken are such that the chances of an accident occurring are so remote. This is discussed in the report on the Oak Ridge accident (*12*) and the recommendation is made that process workers should receive regular refresher courses in nuclear safety precautions. It is apparent that much depends on the choice of reliable supervisors; they will be mainly responsible for keeping process workers prepared and for guarding them against the dangers of staleness through over-familiarity.

The provision of health physics supervision and the siting of suitable detecting and measuring instruments throughout the plant should also be a responsibility of a nuclear saftey organization. This work is closely related to the normal duties of the health physicist but does include unusual features. These are discussed at some length in reference 12. Perhaps the most difficult task for the investigating committee at the Oak Ridge incident was the assessment of the total neutron does received by personnel. Whilst much valuable data is included in this report, it is also apparent that a great deal is still to be learned on the problems of monitoring personnel for neutrons. This subject is, however, outside the scope of the present paper.

Whilst the dangers from a criticality excursion must not be underestimated, it is only fair to point out that many chemical plants handling large quantities of fissionable material have been safely operated for more than a decade with complete safety. This remarkable record of safety has been achieved at the expense of plant efficiency. With the increasing use of highly enriched reactor fuels there has been a need for development of chemical plant of more advanced design and these are tending to be built on the geometrically safe pattern.

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11. McLendon, J. D., Wachter, J. W. and Henry, H. F., *Geneva Conference 1958*, Paper 427
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Industrial equipment for noble gases

OVER the past few years Western Detail Manufacturers Ltd. have increasingly concentrated on turning basic ideas developed with the UK Atomic Energy Authority into practicable industrial equipment.

One early project concerned glove box production and it soon became evident that the inert atmosphere in such enclosed spaces should be continuously swept. Further, oxygen, moisture and in some cases nitrogen had to be removed. The extent of such cleansing can be appreciated when it is realized that commercial argon may contain anything up to 250–300 ppm total impurities while general requirements for glove boxes are of the order of 15–25 ppm total impurities; in some cases for vacuum boxes and special processes such as the welding of zirconium, the permissible impurity levels will be as low as 1 to 5 ppm.

Streamlined service

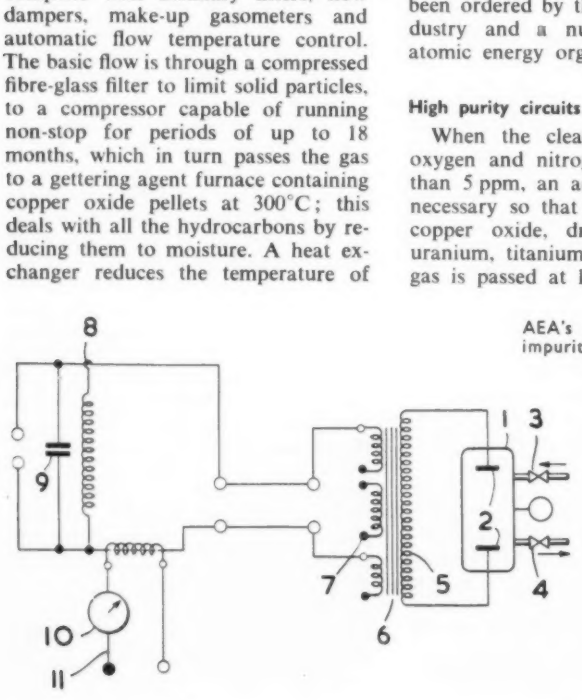
In order to provide a mobile unit capable of continuous service, these argon purifiers have been designed complete with auxiliary filters, flow dampers, make-up gasometers and automatic flow temperature control. The basic flow is through a compressed fibre-glass filter to limit solid particles, to a compressor capable of running non-stop for periods of up to 18 months, which in turn passes the gas to a gettering agent furnace containing copper oxide pellets at 300°C; this deals with all the hydrocarbons by reducing them to moisture. A heat exchanger reduces the temperature of the gas to an ambient level before it passes to a regenerative drier.

The gas is then sent through a second furnace charged with commercial grade calcium at 620°C to remove the oxygen. For the removal of nitrogen, titanium, uranium or zirconium are used as the getter agents and the furnace is heated in the range of 850°C to 1000°C. Titanium in the form of sponge turnings or chips is the favoured material and will deal with oxygen and nitrogen. Following this second furnace is another heat exchanger through which the gas passes on its way to a group of fibre-glass filters to remove any oxides that may have become gas-bound; it eventually reaches a gasholder, which maintains correct pressure in the overall gas purifier system, and balance movements in the associated equipment.

Such a system, operating at atmospheric pressure, will deliver argon with an oxygen content less than 5 ppm, moisture less than 118°F dew point, nitrogen content of between 15 and 20 ppm and a hydrogen content of less than 8 ppm. Already these units have been ordered by the AEA, British industry and a number of overseas atomic energy organizations.

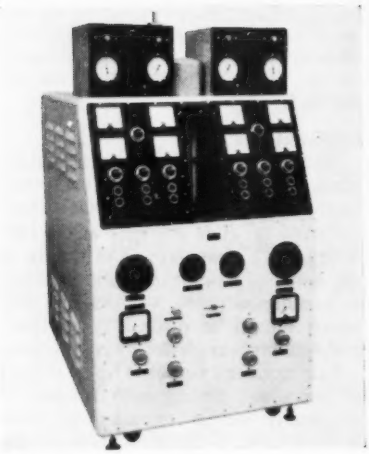
High purity circuits

When the clean up of moisture, oxygen and nitrogen must be better than 5 ppm, an additional furnace is necessary so that the gas flows over copper oxide, driers, calcium then uranium, titanium or zirconium. The gas is passed at least ten times over the getters at pressures of the order of 10 atmospheres resulting in a nitrogen content of less than 5 ppm.



AEA's basic circuit for gas impurity measurement

1 Discharge tube
2 Gold-plated electrodes
3 Inlet for gas
4 Outlet for gas
5 Secondary winding of transformer
6 Transformer
7 Primary winding of transformer
8 Constant voltage transformer
9 Capacitor
10 Ammeter
11 Lead to alarm system



This self-circulating purifier can reduce unwanted elements in argon to less than 5 ppm

New vacuum tube method

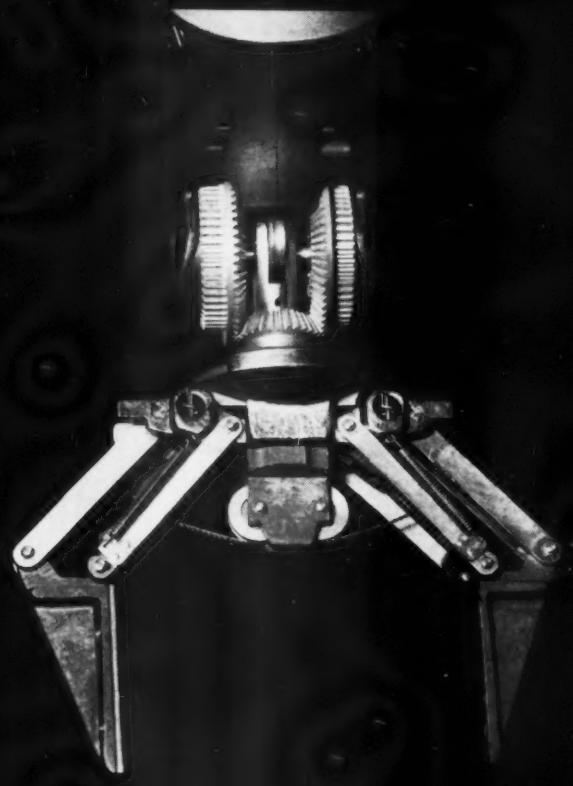
A member of the AEA staff has devised a method of determining the amount of a contaminant in noble gases in which a vacuum discharge tube is used and the Authority has granted a licence on this patent to Western Detail who are now developing the instrument up to an acceptable industrial and scientific standard.

Cutting costs

A new process recently devised by the company is their vacuum pressure injection moulding treatment for which the patent application was made on December 4. This is a method of applying resin-based materials to the surfaces of tubes or wall cavities where an extremely high standard of finish and close tolerances are required.

Any thickness over 0·001 in. can be applied with an accuracy of ± 0·0001 in. and bore diameters, in the case of tubes, can be produced with similar fine limits. Already several cell service tubes have been lined by this method at AERE, Harwell. Here the tubes to be lined were of mild steel and each had three sections of different diameters—a thickness of 0·0015 in. was applied and an overall limit on thickness and concentricity of ± 0·0002 in. was maintained.

Advantages of this process are that any unevenness in the original hole, such as a rough concrete surface, does not in any way lower the accuracy of the finished bore; the coating may be equally well applied in the workshop or on site; it also enables comparatively cheap materials to be used to meet requirements that previously could only be satisfied by machining expensive alloy steels.



Manipulators

The manipulators used at atomic establishments have to operate under exacting conditions. They are constructed of stainless steel and Kanigen plated aluminium and the plate serves two functions. It resists corrosion and, because of the smoothness of the finish, it also assists in decontamination of the component parts from radio-active material; and the combination of stainless steel and Kanigen plated aluminium reduces the electro potential difference between the component parts. These manipulators, manufactured by Savage & Parsons Ltd., are supplied to users all over the world. Kanigen is used on the aluminium parts of the Tong End assembly and the Master Hand assembly.

Kanigen

A HARD & CORROSION RESISTANT PLATE

KANIGEN is a nickel-phosphorus plate deposited by chemical reduction: thickness can be controlled to fine limits and is of complete and uniform coverage.

PROPERTIES:

Composition	92% Nickel 8% Phosphorus
Melting point	890°C.
Electrical resistivity	60 microohm cm.
Hardness	500—1,000 V.P.N. according to heat treatment
Coverage	Extremely uniform

Kanigen can be applied to all ferrous metals, aluminium, copper and brass. The plating plant at Oldbury has now been extended, two extra plating tanks are in operation and enquiries for jobbing plating are welcomed. Full information is available on request.

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KANIGEN

New Product Survey

PLANT · EQUIPMENT · INSTRUMENTS · MATERIALS

MULTI-CHANNEL GAUGING

remote control

A low cost multi-channel gauging system for use in industrial applications has been introduced by Tracerlab. The equipment employs a new type of radiation detector with a range of one million to one. It is adaptable to gauging applications which require the use of multiple detectors; among these are ore, coal, and grain handling systems in which an operator can control the amount of materials being stored in holds, bins, or elevators from a distance. Each probe is moisture sealed and shock proof and contains a transistorized miniature ratemeter, the output of which is displayed on a meter that may be located up to two miles away. A single control and power unit provides power for up to ten probes and if necessary, a multi-point recorder is available to provide a permanent record.

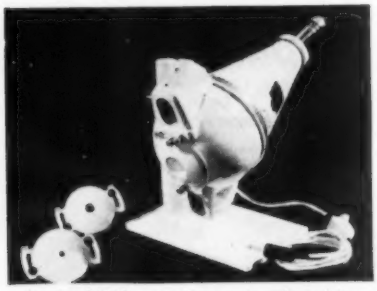
The equipment has a temperature stability range from 0°–175°F; a fast response (less than 2 second time constant); and incorporates dual alarm systems, visual and audible. All units are interchangeable.

Tick **No 208** on reply card

SCINTILLATION COUNTER

lightweight medical unit

A recent addition to the range of nuclear equipment for medical use produced by Ekco is a lightweight scintillation counter, Type N618, with a directional shield, N651. The counter is constructed in a sealed stainless steel container enabling it to be cold-sterilized. The output from the photomultiplier tube is fed via a



In the N618 a continuously adjustable coincident lightspot rangefinder is incorporated

cathode-follower stage to the permanently-attached cable from which connexions can be made to a suitable ratemeter or scaler. The unit normally requires the use of a separate amplifier when connected to ratemeters or scalers requiring a minimum output of 5 volts but it can be connected directly to the Ekco Type N600 ratemeter.

The directional shield retains the scintillation counter by means of a simple clamp ring and it can be fitted with any one of three standard collimators to provide alternative angles of acceptance.

Tick **No 209** on reply card

LIQUID LEVEL INDICATOR

ultra-sensitive probe

In an effort to provide very fine control for water-moderated reactors, the AEA have developed a hunting probe liquid level indicator with a high degree of accuracy—claimed by the Authority for one application to be better than one part in a hundred thousand.

It consists essentially of an electrical probe with a platinum point contact suspended from a stainless steel wire wound on a drum, a split field d.c. motor, a thyratron, and a level indicator. In operation, the probe is lowered on to the surface of the liquid so that when it touches the surface a circuit is completed which fires a thyratron. This reverses the motor so that the probe is raised until contact is broken with the surface of the liquid, when the first sequence is repeated. The speed of the 'hunting' response of the probe is such that the amplitude of motion of the probe is only a few thousandths of an inch.

This design has now been made available for commercial exploitation.

Tick **No 210** on reply card

PROFILING MACHINE

works direct from drawings

By combining a Canadian Westinghouse electronic control system and an optical tracer head of their own design, Hancocks have produced an oxygen cutting machine which eliminates the need for templates and will work direct from pencil line drawings.

The tracer head incorporates a photocell which vibrates with the frequency of the electricity supply. This causes the photocell to scan the white areas on either side of the line drawing and this results in a signal at twice line frequency. Any tendency of the machine to wander from the line or any change in direction of the line itself, i.e. a displacement of the line from the centre of vibration, means that two different amounts of light are focused on the photocell in turn. This results in an error signal which is amplified and used to supply the control winding of a servo motor which in turn is geared to the tracer head and in effect steers it directly above the line. A roller drive enables the machine to operate without physical contact between the tracer head and the drawing.

An optical device centred around a prism is built into the tracer head. A calibrated dial is provided which enables compensation for width of cut to be made on the machine itself instead of having to make drawings of special dimensions. The setting control slightly alters the angle of the prism so that the line of the drawing appears to the photocell to be offset to either one side or the other by an amount corresponding to half the cut width for any given thickness of plate. Thus the finished profiled shapes come out exactly the same size as the pencil drawing.

Plates up to 10 ft × 10 ft in area and 10 in. thick can be dealt with by these machines.

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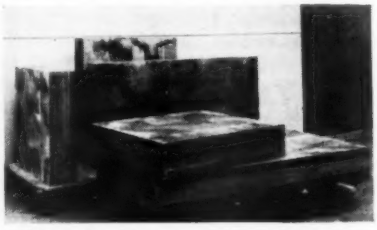
SHIELDING BLOCKS

densified laminated wood

Mechanically strong enough to do without structural support and suitable for intricate shapes, wood laminates with a hydrogen content of 6½% are now available for biological shielding. These Jabroc N shield blocks are formed from beech wood veneers interleaved with synthetic resin and are compressed under high temperature and pressure conditions. For thicknesses greater than 4 in. the blocks are bonded with a cold-setting resin and laminated-wood dowels are used to preserve the shielding properties and ensure accurate assembly. Completed blocks are covered with cadmium sheet and finally enclosed in hot-air welded PVC sheet to protect the cadmium.



Jabroc N prior to coating. Blocks up to 8 ft × 4 ft and 14 ft × 1 ft 4 in. have been produced

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IN BRIEF

High temperature diodes. International Rectifiers have introduced an economical range of 400 PIV-rated silicon diodes. Suitable for operating at temperatures up to 70°C.

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Can you afford a defective tube?

"INTROVIEW"

NON-DESTRUCTIVE TESTING EQUIPMENT

(*Manufactured under licence from I.C.I. Ltd.*)

Recent development of the "Introview" non-destructive testing equipment now enables it to be used for checking grades of stainless steel tubing.

A range of frequencies is employed to facilitate accurate testing by eddy-current principles with an instrument which is equally valuable for production testing and for checking in service.

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INDUSTRIAL DIVISION
Great West Road, Brentford, Middlesex.
Telephone: ISLeworth 1241.

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INDUSTRIAL NEWSDESK

Beryllium fabrication

The ICI have recently brought into commission their new metals works at Witton, a project that has cost some £M10. Included in this plant are facilities for the processing of beryllium and already two-shift work is being carried out. The main output is for fuel cans for the Authority's AGR and beryllium will also be used for certain ancillary equipment.

A subsidiary of TI, Chesterfield Tube Co. Ltd., have concluded a 'know-how' agreement with the Superior Tube Co. of the US for the manufacture of beryllium tubing. This works has already received contracts totalling some £250,000 for beryllium tubing from the AEA, America and France.

US Industry consolidates

A merger has been arranged beween the Refinery Engineering Co. of Tulsa and Vitro Engineering Co. of New York. A new division of Vitro's will be established known as the Treco Construction Division and will be engaged in completing existing power plant projects in the US, Italy and India.

As a development in their long-range plans for the diversification of their activities, General Mills Inc. have purchased Magnaflux Corporation of Chicago, US pioneer in the development of techniques and equipment for the non-destructive detection of flaws.

The Invar Electronics Corp., manufacturers of solid state power supplies and electronic instruments, have been acquired by Telemeter Magnetics Inc. This will provide Invar with financial support for the development of new products.

Electro Powerpacs, Inc., a subsidiary of Hydra-Power Corporation, has absorbed Dormitzer Electric & Manufacturing Co. Inc., who developed and manufactured throwover emergency lighting systems and equipment. A consolidated sales programme is now being formulated for the three companies.

Export drive stepped up

As part of its programme of integration, Associated Electrical Industries Ltd. have established a number of selling companies overseas trading in the name of AEI. The first to become operative was AEI (Canada) Ltd. and since November 1 a further four companies have started operations. These are located at Salisbury, Southern Rhodesia; Johannesburg, South Africa; Wellington, New Zealand; and Rio de Janeiro, Brazil.

Negotiations are being conducted between Elliott-Automation Ltd. and Manufacture de Machines du Haut-Rhin SA, of Mulhouse, for the manufacture of Elliott's equipment under licence in France.

As part of an extensive sales tour of Southern Europe and the Middle East, Mr. L. A. Johnson of Detel Products Ltd. has visited Rome. He discussed with the Italians the application of his company's protective coatings for Italian nuclear installations at present under construction.

A new company has been set up in Australia, International Computers & Tabulators Australia Pty. Ltd., to take over the Hollerith and Power-Samas interests. It will be the largest company in the data-processing field in Australasia.

New designs in the UK

The Nuclear Chicago Corporation, NCC, have appointed Continental Distributors Ltd. as their official agents in the UK. Early in 1960 full servicing facilities will be available in London for NCC's measuring instruments.

Production of the Pace 231-R analogue computer has now started at Burgess Hill by Electronic Associates Ltd., a new company formed by Electronic Associates Inc. of Long Beach.

General Dynamic's Electric Boat Division have agreed to Keith Blackman Ltd. manufacturing to their patented design for axial fans with special slotted blade formation. The advantage of this design is that it provides a means of boundary layer control. This type of fan has been installed in all the nuclear-powered submarines built in the US.

To extend their range of compressors, G. & J. Weir Ltd. have concluded an agreement with Clark Bros. Co. Division of Dresser AG to manufacture to Clark's designs. The full range of reciprocating and centrifugal compressors will be interchangeable with the original US-made models and will be available to all the sterling bloc countries.

To meet the demand for high temperature cracked ammonia for use in the heat treatment of metals, the Gas Atmospheres Division of the Incandescent Heat Co. Ltd. are now producing ammonia crackers to the design of the US Drever Co.

Semi-Elements Inc. have appointed L. Light & Co. Ltd. as their sole UK representative. This is expected to facilitate distribution of single crystals of various elements which Semi-Elements make for nuclear and thermoelectric research.

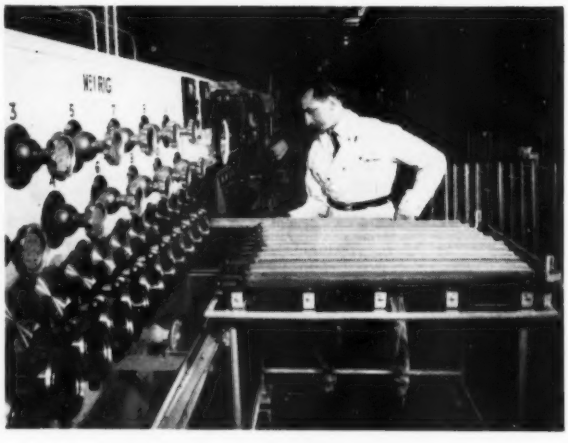
More industrial research

To accelerate development of advanced nuclear fuels, Texas Instruments Inc. have established a branch of its central research laboratory in Attleboro, Mass. It will be located near M & C Nuclear Inc. to take advantage of their facilities and experience in fabricating fuel elements and core components.

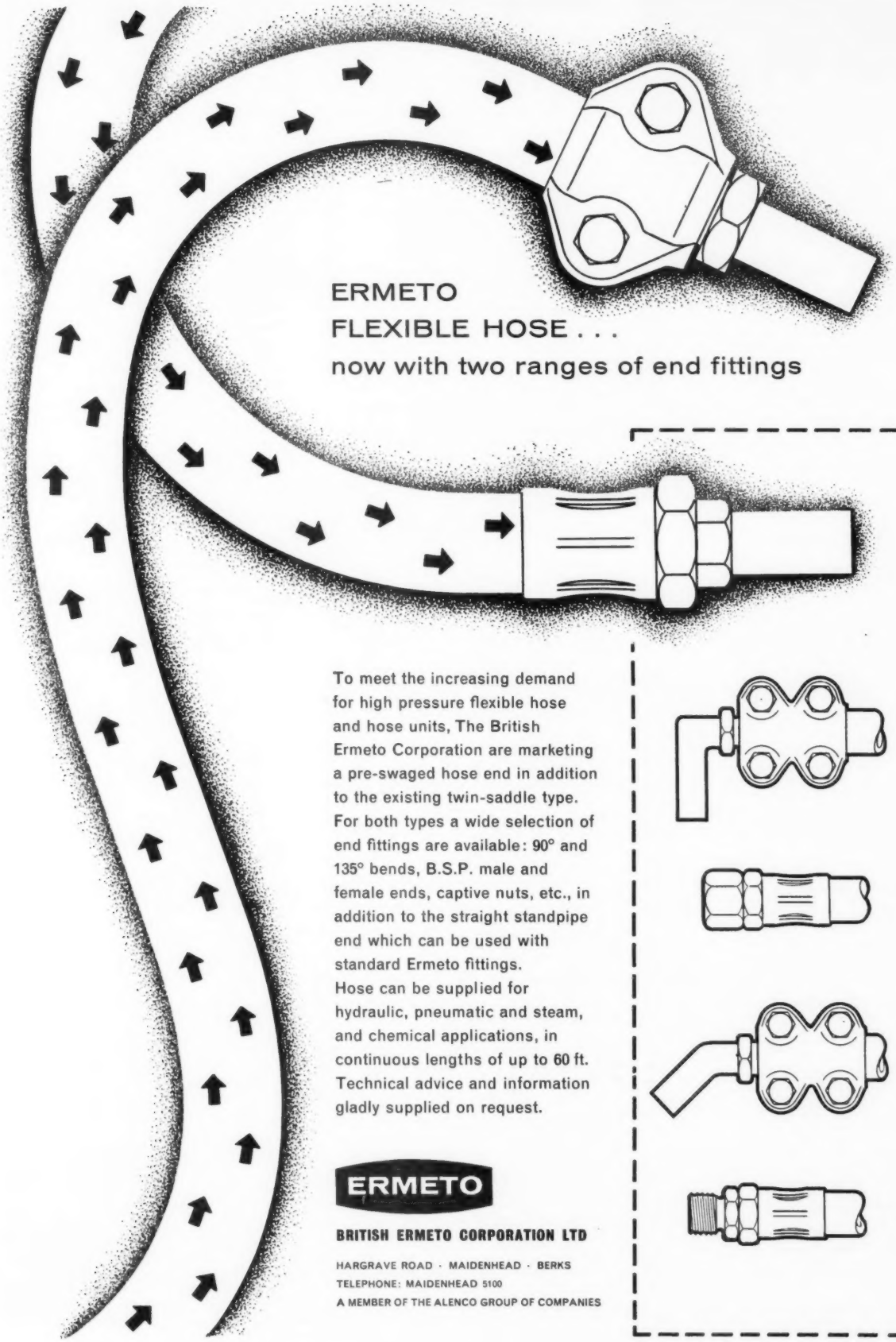
Cambridge Instrument Co. Ltd. have recently opened new research laboratories at their works in Cambridge. They will be used to carry out a three-fold programme—fundamental research into new methods of measurement, exploitation of existing methods in science, industry and medicine, and improvement and development of existing designs.

To produce a new mass spectrometer leak detector and other vacuum technology equipment, Crosby-Teletronics Corp. have formed a vacuum research division. This new facility will be mainly engaged on designing and making test equipment of much greater sensitivity than has hitherto been available.

Increasing demand of computer components and nuclear magnetic resonance equipment has made it necessary for Harvey-Wells Electronics Inc. to expand their research and development division. Nuclear magnetic field control equipment



LEAK TESTING AEA's Springfields Works have now produced over a million uranium fuel rods, each of which is subjected to rigorous tests including mass spectrometry using AEI equipment



ERMETO FLEXIBLE HOSE . . .

now with two ranges of end fittings

To meet the increasing demand for high pressure flexible hose and hose units, The British Ermeto Corporation are marketing a pre-swaged hose end in addition to the existing twin-saddle type. For both types a wide selection of end fittings are available: 90° and 135° bends, B.S.P. male and female ends, captive nuts, etc., in addition to the straight standpipe end which can be used with standard Ermeto fittings. Hose can be supplied for hydraulic, pneumatic and steam, and chemical applications, in continuous lengths of up to 60 ft. Technical advice and information gladly supplied on request.

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UNITS FOR HUNTERSTON With one on site for gas circulator system testing and two approaching completion, the GEC contract for the sixteen gas-circulator motors is on schedule

and high resolution magnets, up to five tons in weight, will also be developed by this division.

Scheduled for completion in the latter part of 1960, the Union Carbide Research Institute near Tarrytown, NY, is now being constructed. When completed it will be used for theoretical and experimental studies on the fundamental physical and chemical principles affecting high-temperature materials.

In brief

New research tool. The United States AEC have placed a $M1 order on High Voltage Engineering Corp for a 10 MeV tandem Van de Graaff particle accelerator.

More manipulators. H. M. Hobson Ltd. has been awarded a contract for the design, manufacture, erection and commissioning of three caves and ten cells at the CEGB's Berkeley research laboratory.

Towards simplification. The first section of the British Standards Institution new Master Schedule of Steel Standards has been issued. This is BS3141 and covers wrought steels and should greatly help in eliminating the needless and uneconomic diversity of output caused by the existence of the large number of earlier sectionized specifications.

Free training. To encourage technicians to study atomic energy, Hungary is allowing students to take 20 hours a week free from their normal employment to study reactor engineering, nuclear electronics or nuclear chemistry.

Trawsfynydd's switchgear. Associated Electrical Industries Ltd. is to supply the CEGB with 275 kV air-blast switchgear to control the output of this station. The value of the contract is £900,000.

First in the Soviet Union. A 4 MeV linear accelerator, designed for X-ray treatment of deep-seated tumours, is to be supplied by Mullard Equipment Ltd. for installation in Moscow. This is the first British equipment of its kind to be ordered by the USSR.

LOOKING AHEAD

MONDAY 4 JANUARY—FRIDAY 29 APRIL
No. 20 Harwell Reactor Course. Applications to the Principal, Reactor School, AERE, Harwell, Didcot, Berks

TUESDAY 5 JANUARY
Heat transfer to two-phase gas/liquid systems J. A. R. Bennett, J. G. Collier, H. R. C. Pratt and J. D. Thornton, and *Pressure drop and hold-up two-phase flow* J. G. Collier, J. D. Thornton and J. A. R. Bennett, the Institution of Chemical Engineers 5.30 at the Geological Society, Burlington House, London, W1
The Use of Plastics in Engineering C. L. Child, Technical Service and Development Dept. ICI, the Institution of Plant Engineers 7.30 at the White Lion Hotel, Church St., Peterborough

TUESDAY 5—THURSDAY 7 JANUARY
Recent Mechanical Engineering Developments in Automatic Control (Symposium) The Institution of Mechanical Engineers, applications to the Secretary, 1 Birdcage Walk, Westminster, London, SW1

WEDNESDAY 6 JANUARY
Non-destructive Testing E. McCabe, Institution of Electrical Engineers, Southern Centre, 6.30 at CEEB Offices, Portsmouth

MONDAY 11—SUNDAY 24 JANUARY
Effects of Atomic Radiation. Scientific Committee of the General Assembly at UN Headquarters, New York, USA

TUESDAY 12 JANUARY
Submersible Pumping Plant H. H. Anderson, BSc, and W. G. Crawford, BSc, Institution of Electrical Engineers, North Eastern Centre, 7.00 at Workington College of Further Education

WEDNESDAY 13 JANUARY
Electrification of the UKAEA Industrial Group Factories J. W. Binns and W. J. Outram MEng, Institution of Electrical Engineers, North Lancashire Sub-Centre, 7.15 at NWEB Demonstration Theatre, Friargate, Preston
Health Physics and Nuclear Power B. C. Godbold, BSc, AInstP, AMIEE, Women's Engineering Society 7.00 at Hope House, 45 Great Peter St., Westminster, London, SW1

THURSDAY 14 JANUARY
Pipeline Cleaning Techniques M. Webb, BSc, the Institution of Plant Engineers 7.00 at Roadway House, Oxford St., Newcastle-upon-Tyne

THURSDAY 14—FRIDAY 15 JANUARY
Problems of Radioactivity at Water and Sewage Works Short course of lectures, applications to the Registrar, The Manchester College of Science and Technology, Manchester, 1

FRIDAY 15 JANUARY
Reactor Physics (15 week course) Technical University of Trondheim, Norway
Postgraduate Course in Nuclear Engineering for Engineers (22 week course) Institute of Technology. Applications to University of Lausanne, Avenue de Cour 33, Lausanne, Switzerland

MONDAY 18 JANUARY
The Design of Electro-Mechanical Auxiliaries directly associated with Power-Producing Reactors A. E. Harwood, P. Scott, MA. and B. H. Stonehouse, BSc, Institution of Electrical Engineers, Western Supply Group. 6.00 at South Wales Institute of Engineers, Park Place, Cardiff

MONDAY 18 JANUARY
The Engineering Problems anticipated in Space Travel M. J. Brennan, BSc, MIMechE, FRAeS, the Institution of Plant Engineers 7.00 at the Meeting Hall of the Institution of Mechanical Engineers, 1 Birdcage Walk, London, SW1

MONDAY 18—FRIDAY 22 JANUARY
44th Exhibition of Scientific Instruments and Apparatus by The Physical Society at the Royal Horticultural Society's Halls, Westminster, London, SW1

WEDNESDAY 20 JANUARY
Fine Measurement John R. Adams, BSc, AMIMechE. The Institution of Plant Engineers 7.30 at the Bell Hotel, Leicester

WEDNESDAY 20—THURSDAY 21 JANUARY
Reliability of Digital Computer Systems A series of discussion meetings at the Institution of Electrical Engineers, Savoy Place, London, WC2

THURSDAY 21 JANUARY
Serial Gravity Concentration—A New Tool in Mineral Processing J. H. Harris, MIMM, and, *Use of Moving Bed Ion Exchange in the Recovery of Uranium at Can-Met Exploration Ltd., Blind River, Ont.* P. D. R. Maltby, AMIMM, the Institution of Mining and Metallurgy 5.00 at the Geological Society, Burlington House, Piccadilly, London, W1

TUESDAY 26 JANUARY
Control and Instrumentation of Marine Reactors R. Anscombe, OBE, and F. Hutber, Institute of Marine Engineers 5.30 at the Memorial Building, 76 Mark Lane, London, EC3

THURSDAY 28 JANUARY
Instrumentation Dr. R. H. Baulk, The Institution of Plant Engineers 7.30 at the Grand Hotel, Sheffield

LOOKING FURTHER AHEAD

SUNDAY 3—FRIDAY 8 APRIL
Sixth Nuclear Congress, Nuclear Engineering Conference, International Atomic Exhibition and Eighth Atomic Energy in Industry Conference at New York, USA

TUESDAY 5—SATURDAY 9 APRIL
Ninth Electrical Engineers' Exhibition at Earls Court, London, SW5

TUESDAY 19—FRIDAY 22 APRIL
International Symposium on the Metallurgy of Plutonium. Session on Nuclear Fuels, Société Française de Métallurgie and French Atomic Energy Commission at Grenoble, France

FRIDAY 29—SATURDAY 30 APRIL
Convention on Thermonuclear Processes. The Institution of Electrical Engineers at Savoy Place, London, WC2

MONDAY 9—FRIDAY 20 MAY
Special Harwell Course for Senior Technical Executives. Applications to the Principal, Reactor School, AERE, Harwell, Didcot, Berks

MONDAY 16—WEDNESDAY 25 MAY
Course on Reactor Environmental Health Problems, Robert A. Taft Sanitary Engineering Centre at Cincinnati, Ohio, USA

MONDAY 23 MAY—FRIDAY 3 JUNE
Fourth Reactor Control and Instrumentation Course. Applications to the Principal, Reactor School, AERE, Harwell, Didcot, Berks

SUNDAY 5—THURSDAY 9 JUNE
Sectional Meeting of the World Power Conference in Madrid. Applications to the Secretary, British National Committee, World Power Conference, 201-2 Grand Bldgs., Trafalgar Sq., London, WC2

SUNDAY 12—WEDNESDAY 15 JUNE
Sixth Annual Meeting of the Amerian Nuclear Society at Chicago, Illinois, USA

MONDAY 13—WEDNESDAY 29 JUNE
Seventh International Nuclear Congress & Exhibition on Electronics & Atomic Energy. National Committee for Nuclear Research at Rome, Italy

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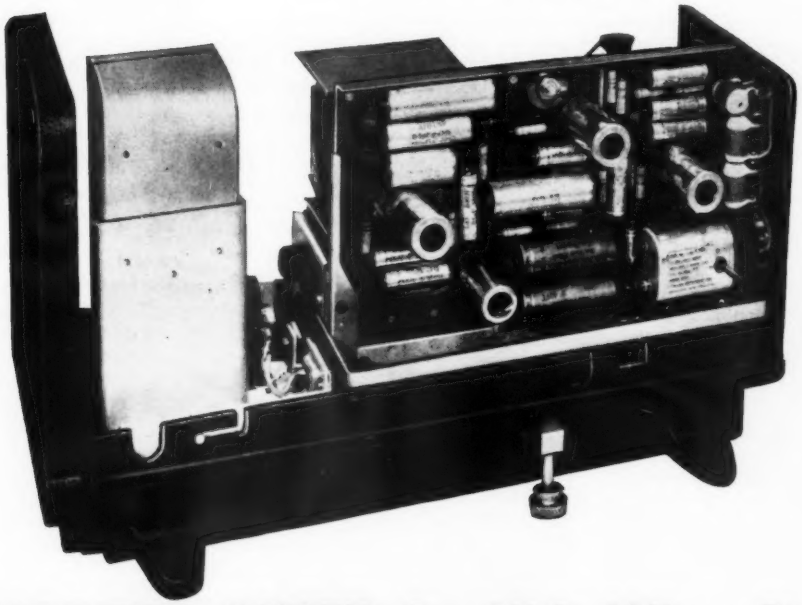

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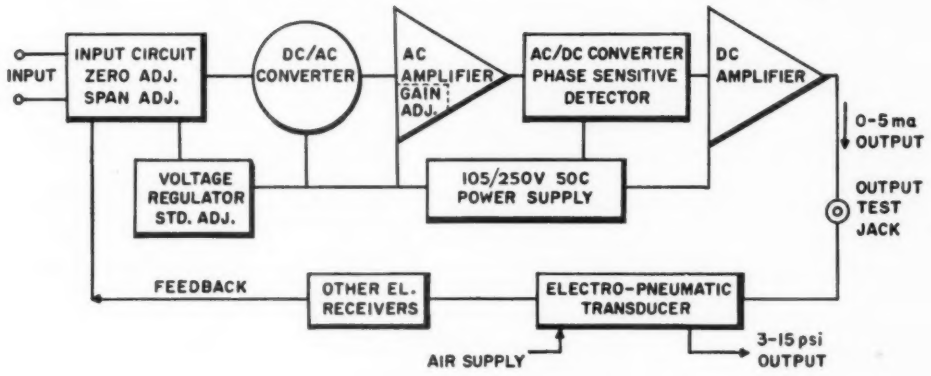

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They said...

points from papers, speeches, conferences

Fuel element efficiency

Calder Hall fuel element failures and troubles anticipated in the present generation of CEGB stations, with possible solutions, were discussed by Sir John Cockcroft in, a speech at Delft, Holland, recently. Referring to Calder Hall he said that 'in the early stages of operation a complete change of charge took about ten weeks, but this has now been reduced to about 4½ weeks (the fuel elements in these reactors cannot be changed under load). Between these major changes of fuel elements the reactors have generally operated with load factors of about 90%. Of the remaining 10% of lost time, half is accounted for by unscheduled maintenance, two or three per cent by experimental work and the remainder by the occasional need to change faulty fuel elements. A large proportion of the 27 failures have occurred in the colder fuel elements at the lowest position in a reactor channel. Only one failure of this type has occurred in the position above the lowest where the fuel elements are at a temperature about 100 degrees hotter than in the lowest position. These failures are due to the strains developed in the magnox can by the small end-growth of uranium and the lack of ductibility of magnox at the low temperature'.

Reverting to more general terms on power production, Sir John said 'During the course of nuclear power development a convention has grown up that natural uranium fuel elements should be expected to achieve a burnup of 3000 MWd/T and uranium oxide fuel elements should be expected to achieve a burnup of 10,000 MWd/T. There is of course no precise technical validity for either of these figures. Burnup has an upper limit for any reactor depending on the nuclear characteristics of the reactor. For natural uranium reactors of the Electricity Board type, the reactivity, or neutron balance, should permit an *average* burnup of 4500 MWd/T to be achieved. The corresponding burnup for reactors using uranium oxide fuel elements will depend on the degree of enrichment of the fuel and they can of course be designed so that reactivity considerations will permit burnup of 10,000 MWd/T to be achieved'.

These figures of burnup do not compare favourably with those at present being used by Euratom — there 18,000 MWd/T is the current rating (see *Cross-Section*, November 1959)—but Sir John Cockcroft stated that up to mid July, 1959, some 90,000 fuel elements had been irradiated and the maximum burnup achieved was 1300MWd/T and a maximum dwelling-time in the reactor of about 19 months.

Referring to the stations at present under construction, the speaker noted that the fuel elements will be operating

Sir JOHN
hopes for greater efficiency

at a temperature of about 30°C higher than normal for the Calder Hall-type of fuel elements. This will possibly lead to a swelling of the uranium metal due to the internal pressure of the fission gases. Against this, the higher operating temperature may lead to the elimination of graphite sleeving and he said 'since the Electricity Board reactors and the Latina reactor operates with higher graphite temperatures, it is possible for the designers of some of the stations to dispense with sleeves and I understand that sleeves are not to be fitted at Latina'.

Keeping close control

Another aspect of reactor operation reviewed in this address was that of power and flux oscillations. Sir John said 'we have observed no evidence in Calder reactors of the slow radial and axial oscillations of power and flux reported in the Shippingport reactor. The theory of these oscillations, which are due to xenon accumulation, is however well understood and they may be expected to occur in the larger reactors of the Electricity Board power stations. We have carried out an extensive series of calculations on these instabilities . . . the results show that the radial instability will have periods of about 25 minutes in a typical reactor. The oscillations will be automatically reduced to small amplitudes by installing about nine fine sector controllers for radial and azimuthal distributions'.

'Calculations on the axial oscillations, tracing these by one dimensional methods, suggest that axial instabilities are unlikely to arise. Three dimensional calculations are *now* being carried out. The results will show whether any additional controls will be required to suppress these oscillations'.

AIF talks rockets

In Washington the potentialities of nuclear energy were being rated at a rather higher level. Dr. Hugh L. Dryden, deputy administrator of the US National Aeronautics & Space Administration, when addressing the annual conference of the Atomic Industrial Forum at the beginning of November last, said that a rocket powered by a reactor may be ready to explore interplanetary space within the next ten years.

The conclusions reached by the speaker were that 'the potentialities of the use of nuclear power in the exploration of space are very great indeed, both for primary propulsive power and auxiliary power. In fact there are certain tasks involving large payloads accelerated to high velocities for deep space missions than cannot be accomplished by any other practicable means'.

After reviewing the stages of nuclear application to the problems of space propulsion and underlining that the conventional application of nuclear fission to the rocket is a reactor used to add heat to a propellant, Dr. Dryden said 'the great advance in nuclear technology required for space application is bound to bring benefits to all nuclear technology . . . Project Rover, a cooperative programme between the US Atomic Energy Commission and National Aeronautics & Space Administration, is intended to explore and demonstrate the feasibility of developing such a system'.

According to T. P. Cotter of the Los Alamos Laboratory in a recent paper, the experiments now in progress as part of Project Rover, represent a first but important step toward the development of a system, which will not at first be spectacularly better than chemical systems but which has greater potentiality for development well beyond that possible for chemical systems.

More processing

At a discussion in November last at the Institution of Chemical Engineers on the second uranium plant, Springfields, Mr. L. P. Shortis of AEA said that this has been operating for 15 months. He went on to say that as the design calculations had not been borne out in practice, 'in future plants they would try to avoid stage interdependence.'

EKCO ELECTRONICS
for Reactor Instrumentation

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THE RANGE OF INSTRUMENTS DEVELOPED INCLUDES:

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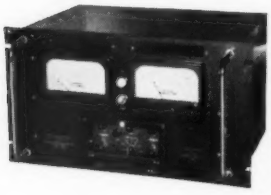
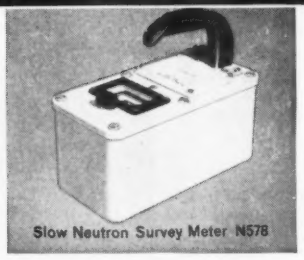
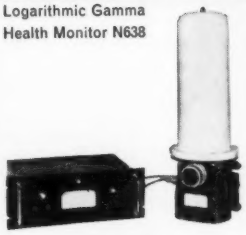


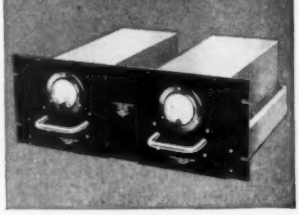


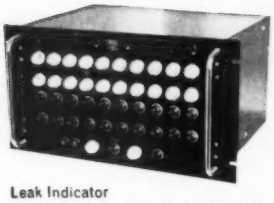
Slow Neutron Survey Meter N578

Logarithmic Gamma Health Monitor N638

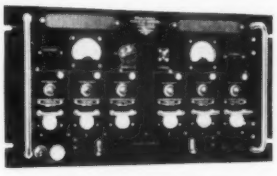


Battery Box Assemblies 1510A

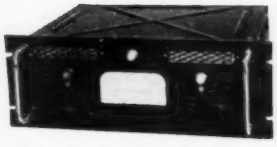




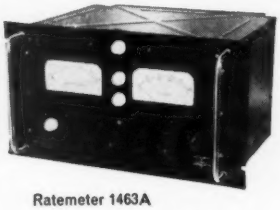
Leak Indicator (for external heavy water leak) 1509A



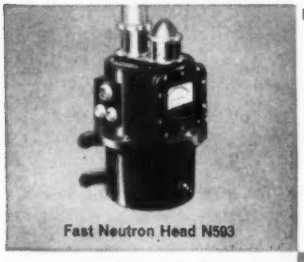
Misalignment Indicator (for coarse control arms) 1512A



Shut-Down Amplifier (with start-up facilities and shut-down state trip) N637

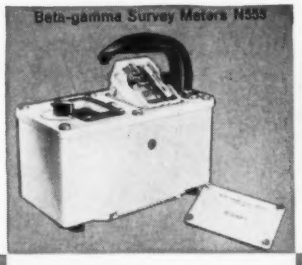


Ratemeter 1463A



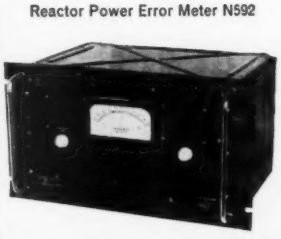
Fast Neutron Head N593

Resistance Thermometer Trip Unit N643



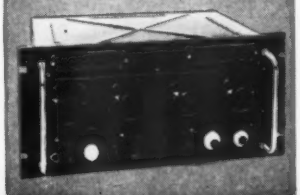
Beta-gamma Survey Meters N335

Reactor Power Error Meter N592



Thermocouple Trip Amplifier N642

Decade Voltage and Current Generator (general purpose test unit) N631



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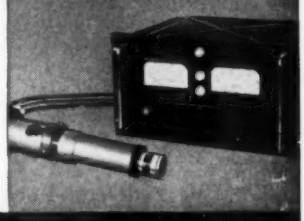
Effluent Monitor N657



EKCO ahead in reactor instrumentation

WPS 381

NAMES IN THE NEWS

Capt. R. S. Hawkins, RN, has been appointed Deputy Director of Marine Engineering (Rear Admiral Nuclear Propulsion) in succession to **Rear Adml. G. A. M. Wilson** who has held the post

Capt. R. S. HAWKINS, RN. nuclear responsibility

since it was first established in 1957. Capt. Hawkins will be responsible for implementing the findings of the Galbraith Committee which are expected to be announced shortly.

The American AEC has established a post of Assistant General Manager with responsibility for the Commission's activities in the fields of licensing, health and safety. **Mr. William F. Finan,** previously assistant director for management and organization of the Bureau of the Budget, has been appointed to the post.

The managing director, **Mr. J. W. Meredith,** of Huntington, Herberlein & Co. Ltd., a subsidiary of Simon-Carves Ltd., has been appointed a director of the parent company.

The fourth Enrico Fermi award, worth some $50,000, has been awarded to the nuclear scientist, **Dr. Glenn T. Seaborg,** Chancellor of the University of California 'for discoveries of plutonium and several additional elements and for leadership in the development of nuclear chemistry and atomic energy.'

Mr. T. B. Ellis has been appointed Secretary of The General Electric Co. Ltd., and has taken over from **Mr. T. B. O. Kerr** who was recently appointed director for finance and administration (see last month's *Names in the News*).

General Dynamics Corporation's General Atomic Division has appointed **Mr. George E. Kidd** as Head of the Mechanical Engineering Division at the John Jay Hopkins Laboratory for Pure and Applied Science.

Following the retirement in December of **Mr. James E. Brinckerhoff** after 40 years' service The Babcock & Wilcox Company has appointed **Mr. Robert A. Barr** as vice president in charge of the Refractories division.

R. A. BARR, leads B & W Refractories division

After being Head of the Fatigue Department of the Bristol Aircraft Co. for six years, **Mr. Tibor Hass,** Dipl.Ing, AMIMechE, AFRAeS, has joined the British Welding Research Association as Head of the Design Section in the newly formed Members' Service Department.

Two British scientists, **Professor John T. Randall,** Wheatstone Professor of Physics at London University, and **Dr. Henry A. H. Boot,** Senior Principal Scientific Officer, Royal Naval Scientific Service, have received the 1959 John Scott medal and award for their invention of the cavity magnetron.

To consolidate their position in South America, **Mr. R. J. Horlock** of the export department of John Thompson Ltd. is moving to Buenos Aires to manage a new branch office for the John Thompson Group.

R. J. HORLOCK to take charge in South America

Dr. Mostafa B. Talaat, an Egyptian-born engineer, has joined the Nuclear Division of the Martin Company to direct all research and development work on energy conversion. He will concentrate especially on thermoelectric, thermionic and magneto-hydrodynamic systems.

Dr. M. B. TALAAT, thermonuclear interests

The American Timoshenko Medal, given for distinguished contributions to the basic engineering science of applied mechanics, has been awarded this year to **Sir Richard V. Southwell,** former Rector of the Imperial College.

Lieut.-Cmdr. D. F. Battison, RN(retd.), has been appointed sales manager of Electropol Processing Ltd.

CATALOGUES AND BULLETINS

Moby Dick. Mitchell Engineering have issued a booklet reviewing their mercantile nuclear power submarine project. Cargo handling and navigational details are included.

Tick **No 214** on reply card

Better pipe lines. 'Design of welded pipe fittings' is the title of a new handbook published by the British Welding Research Association; it gives extensive stress measurements as well as practical design applications. Copies may be had from the association, price 15s.

Tick **No 215** on reply card

Research equipment. Two leaflets from Spembly describe two new products—Capacitor Discharge Welding Apparatus (No 26) for fine wire welding and Hot Plates (No 28) which were designed for hot cell use at Dounreay.

Tick **No 216** on reply card

Export service. The latest version of Negretti & Zambra's general catalogue has been issued in German. This describes their range of temperature measuring equipment and is the fifteenth overseas version.

Tick **No 217** on reply card

Remote control. Applicable for a wide range of industries, the Armstrong Actuator is fully described, together with its accessories and possible circuits, in a new booklet published by the makers.

Tick **No 218** on reply card

Materials for high temperature. Information sheet M897/1 gives the salient features of Jessop-Saville's forging alloys which have been particularly designed for high temperature applications.

Tick **No 219** on reply card

EFFI Bulletin. The first number has been published by the Electronic Forum for Industry and includes several articles on the industrial application of computers.

Tick **No 220** on reply card

Wiring details. A new leaflet 'the products of Hellermann Ltd.' describes this company's products and tools for electrical and electronic installations.

Tick **No 221** on reply card

Computer applications. Four data sheets have been issued by Solartron covering their digital data recorder, analogue tutor, diode function generator and X-ray spectrometer.

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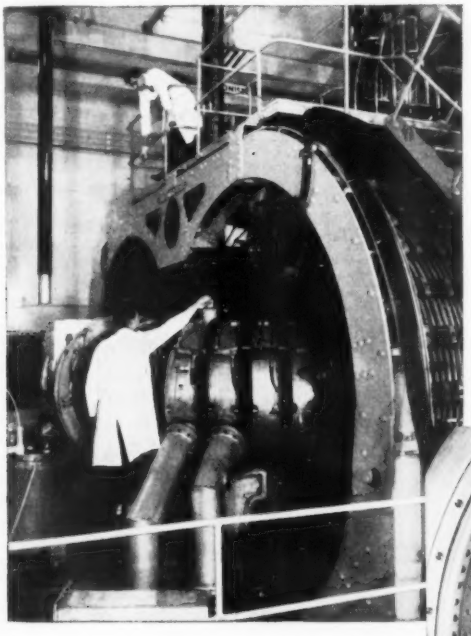
TEDDINGTON BELLOWS
and Nuclear Power
HARWELL PAYS A TRIBUTE

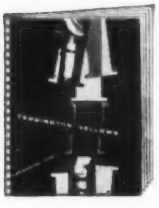
Harwell top research scientists have freely acknowledged * that recent improvements in the operational efficiency of Zeta owe much to the introduction of a corrugated stainless steel liner inside the aluminium 'torus'. Having decided to use such a liner, they turned to Teddington engineers who, out of their experience in adapting their bellows expansion joints to various demands in a wide field of industry, produced exactly what was required for satisfactory running over long periods.

* *In a paper read before the I.E.E. on 29|30 April 1959 by Mr. J. T. D. Mitchell of the U.K.A.E.A., Harwell*



In Zeta, experiments towards controlling fusion have resulted in gas temperatures of several million degrees centigrade being achieved for millisecond periods. View showing the torus.

This stainless steel liner has improved operational characteristics and requires less maintainance than the original aluminium liner system. Here is part of the twelve welded sections of Teddington stainless steel bellows tube of wall thickness 0·017″; it has 2½ convolutions per inch of a depth of 0·75″. The bellows is 38 inch bore and the whole toroidal bellows assembly has an axial length of 37 feet and an electrical resistance of 0·02 ohms.



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Illustrated descriptions are given of the many and varied problems that Teddington Bellows Expansion Joints can overcome. If you did not secure your copy at the Engineering Exhibition, please write for one.

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Book Reviews

American processing

Uranium Production Technology by C. D. Harrington and A. E. Ruehle 1959: Van Nostrand 579 pp Price 131s. 6d.

This is one of the most comprehensive works published to date on the manufacturing processes of uranium and its compounds, and it should appeal both to the person already working in this field and to the advanced student.

It describes in the greatest detail the American methods for processing uranium for use in both cartridge manufacture and in uranium hexafluoride. There is an excellent chapter devoted to the processing of uranium compounds using advanced methods such as ion exchange and fluidized solids techniques for the manufacture of both uranium tetrafluoride and uranium hexafluoride. Very little information appears to have been withheld and cost figures for some of the processes are included for completeness. This is most welcome to the reader who is interested in comparing the costs of American and British methods of manufacture. The last chapter is devoted to health hazard control and the reader once again is fortunate is being provided with this information, which is not often included in this type of publication.

For the industrial chemist it is a little disappointing not to have been given more information regarding the control engineering associated with the American processes and very few details of instrumentation are given. This is rather surprising as the tendency these days is towards fully automatically controlled processes. Some of the chapters on the other hand can be criticized for giving too much detail, in particular the one describing the now almost obsolete ether purification process. It is difficult at times to decide for whom parts of the chapters three to six have been written. The information given is certainly too detailed for the student and at the same time is too mundane for the industrial chemist employed in the uranium industry; for example, an explanation of how uranium ore is tipped from the drums seems rather superfluous. Detail of this type would perhaps better have been included in a history of the development of the processing of uranium and the book as a consequence could have been made smaller and cheaper.

These are small criticisms, however, in a work running into more than 500 pages and the book as a whole should be received with enthusiasm by all those interested in the manufacturing processes of uranium and its compounds.

E. Hawthorn

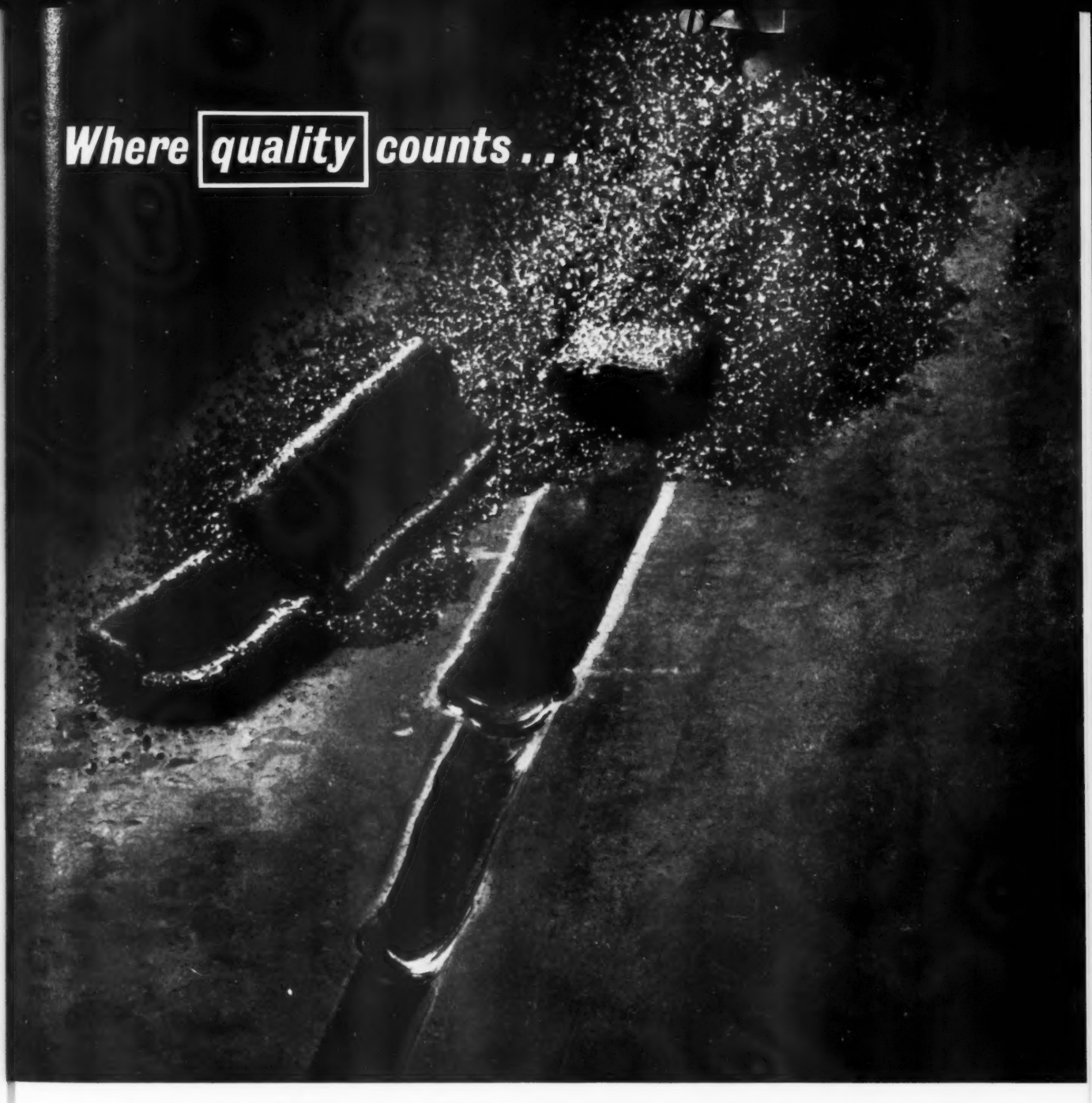
Free electron physics

Electron Physics by O. Klemperer, 1959 London: Butterworths, and New York: Academic Press Inc 248 pp 32s 6d and $7.00

In a manner ideally suited to undergraduate students this book deals with the physics of the free electron. The author, with his wide experience of research and of University teaching, has carefully chosen the order and form of presentation. The book is divided into two parts. After a short historical introduction, Part I deals with the more practical aspect of the subject, namely the motion of electrons in electric and magnetic fields, electron optics, the effects of high space-charge density and a survey of methods of detection. Although perhaps the topic is not immediately relevant, the reviewer would have wished to see included in the section on electron-focusing and velocity-selecting devices some discussion of the behaviour of ions, since the problems encountered in mass spectroscopy are virtually identical with some of those analysed. Part II is concerned with the more fundamental properties of the electron, and after a critical survey of the experimental work on the measurement of charge and charge to mass ratio, deals with the relativistic behaviour, the wave-like properties and the spin and magnetic moment of the electron.

The graduate who is confronted with a problem in electronic engineering will probably find Part I more useful and, although no single topic is dealt with in a manner to satisfy the specialist, it will no doubt clarify his thoughts and provide references for further study. For the student an appendix is included at the end of the book in which important relationships are derived, and at the end of each chapter are numerous problems, some of which are taken from London BSc Special Physics papers set over the past ten years. Adequate references also provide more detailed information on special topics. The book is well produced, the printing and lay-out are of a high standard, and all diagrams are clearly labelled.

K. J. Close



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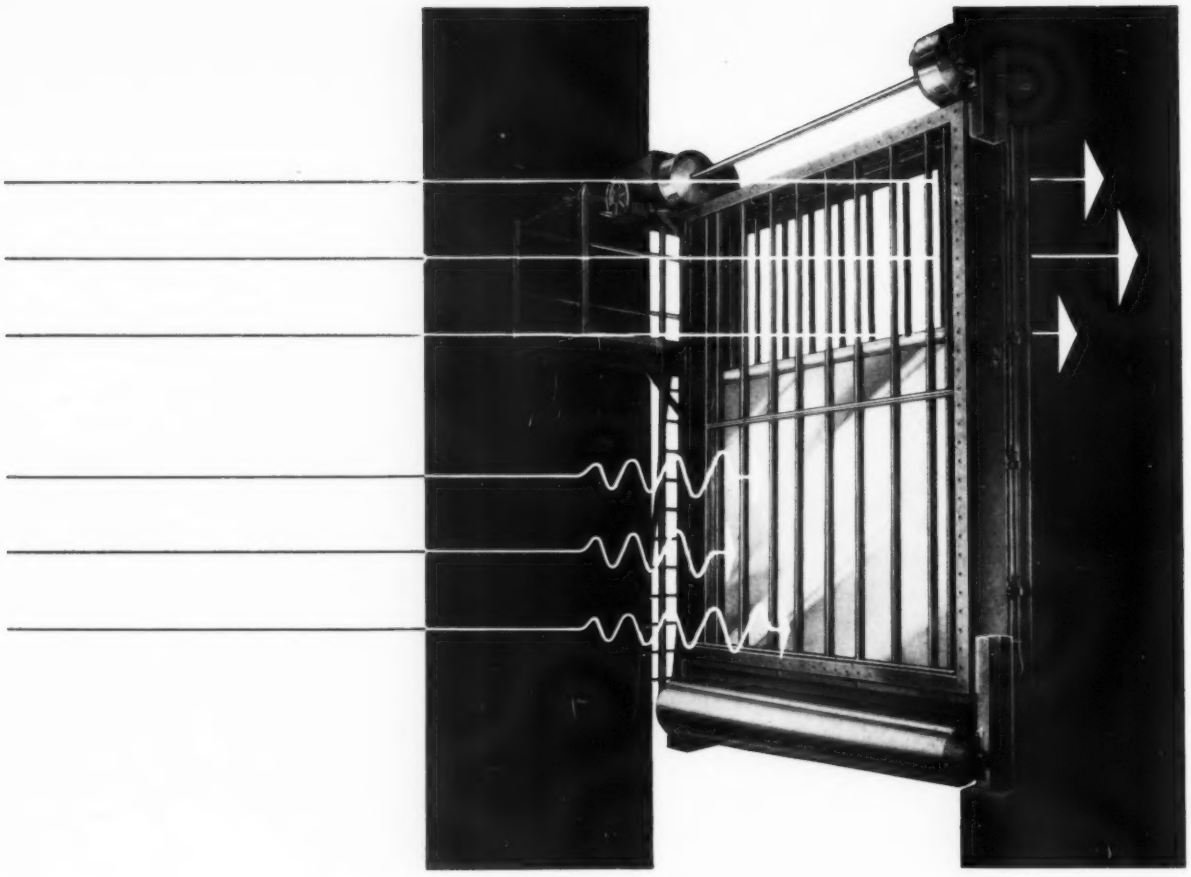

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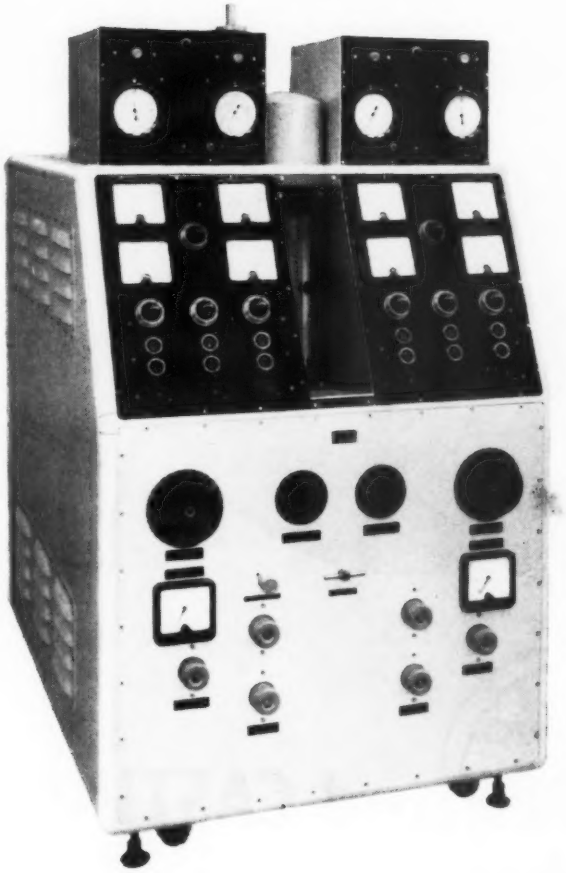

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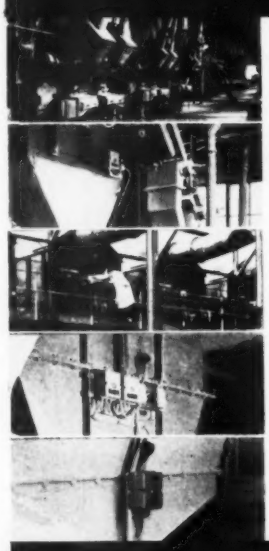

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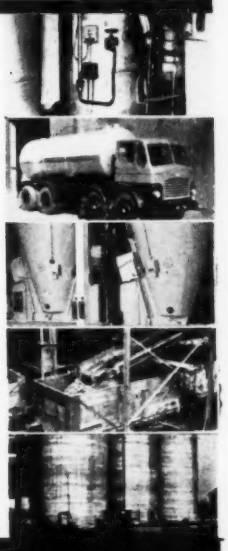

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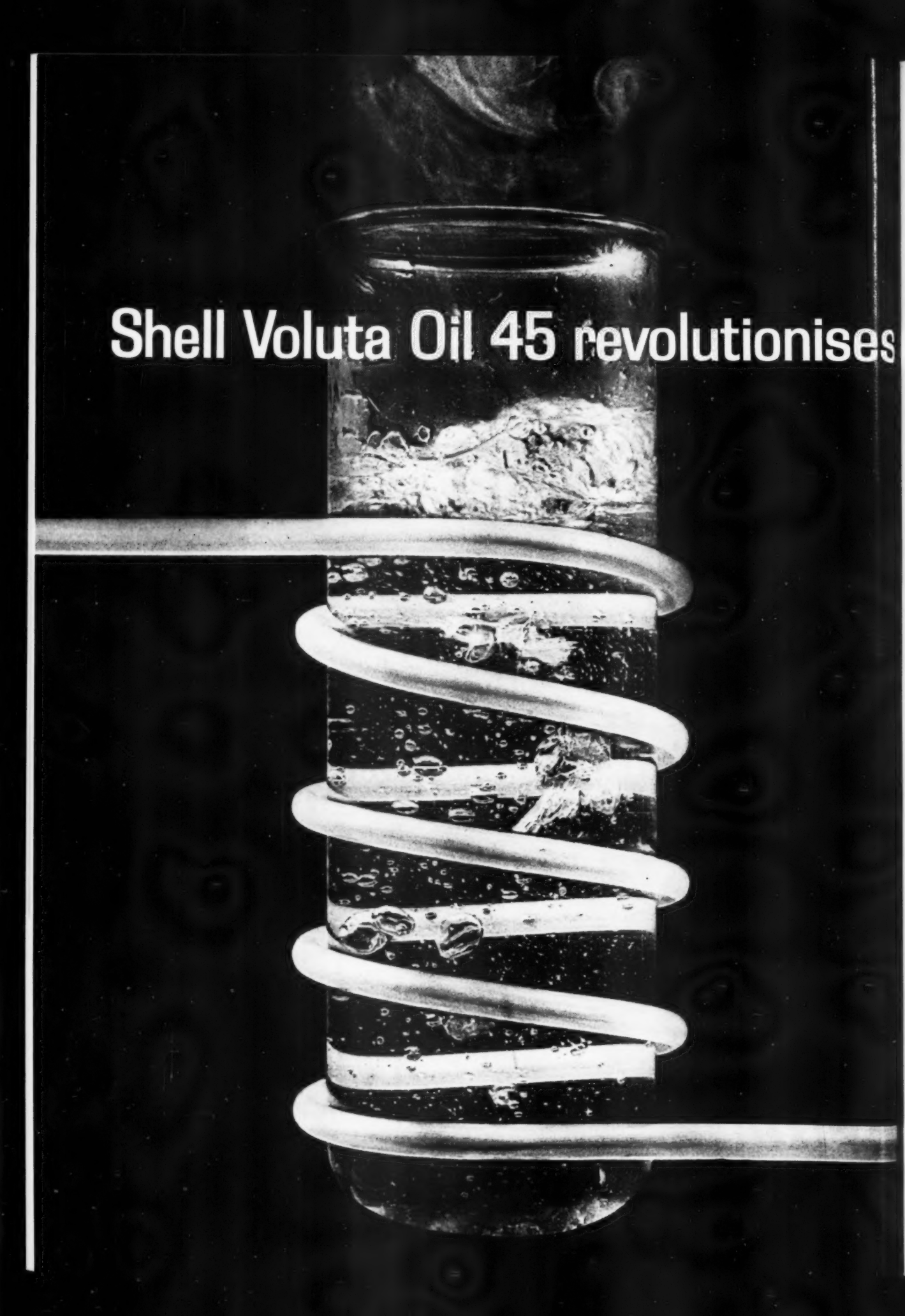
Shell Voluta Oil 45 revolutionises h

heat exchange practice

Before Shell produced Voluta Oil 45 it was thought that oils which were to be used for heat exchange purposes must have a high flashpoint —to reduce fire risk, and a high viscosity—to prevent excessive leakage through pump glands and to provide adequate lubrication for pump bearings at high temperatures. Heat exchange systems containing these viscous oils, however, were sluggish, particularly when started up from cold. The oil circulated slowly over the source of heat and suffered thermal decomposition, or "cracking". This, in turn, produced low flashpoint materials and carbon which insulated the heating surface.

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The moral of the story is that Shell research is supremely applicational. The centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organisation have any major lubricating problems, it pays to get in touch with your local supplier of Shell Industrial Lubricants.

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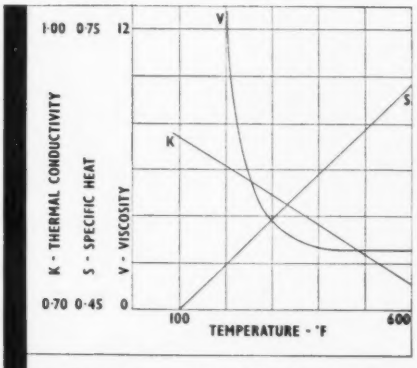

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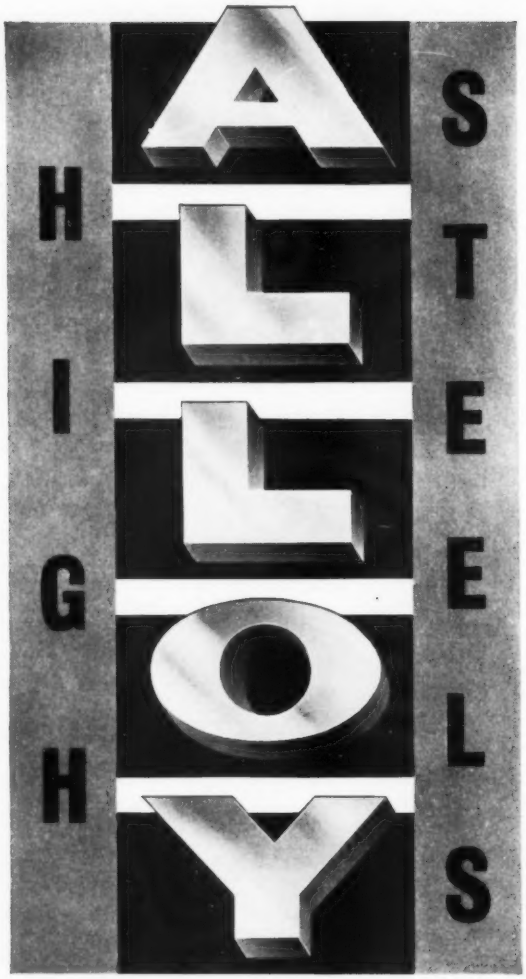

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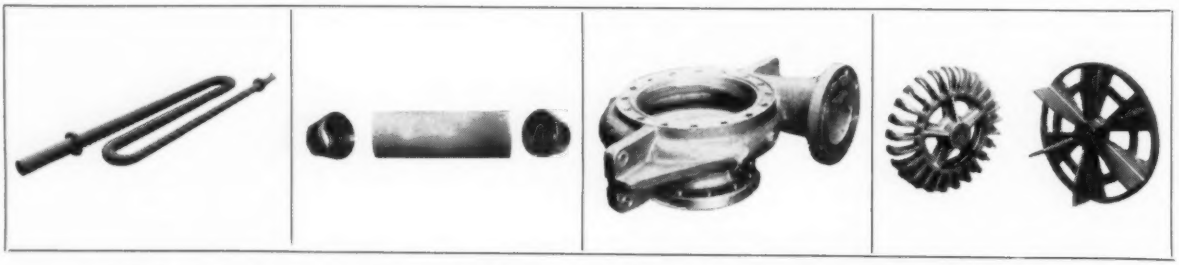

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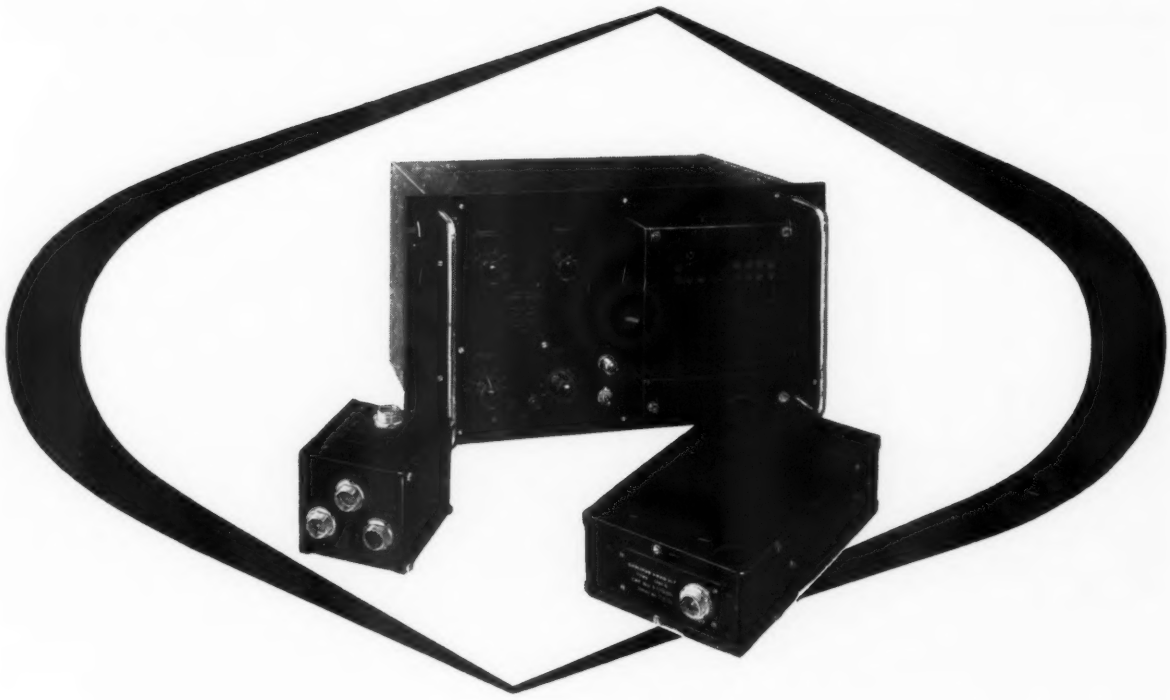

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Differentiating Time Constants :
0.08μs to 8μs in 7 steps plus 250μs step.
Output : Positive 50V. for 1% linearity. Saturation 75V.
Upper Frequency Response : { 1.25dB to 1.4 Mc/s. / 3.25dB to 2.8 Mc/s.

H.F. Head Amplifier.
Input : 10 megohms. 10pf.
Output : Designed to feed into 100 ohm matched cable.
Gain : 31.5dB.
Filter : E.H.T. Filter suitable for voltages up to 3kV.

Cathode Follower.
Input : 10 megohms, 10 pf.
Output : Designed to feed into 100 ohm matched cable.
Insertion Loss : 23dB.
Filter : As in H.F. Head Amplifier.

Stand 24 Physical Society Exhibition
OLD HORTICULTURAL HALL WESTMINSTER S.W.1.
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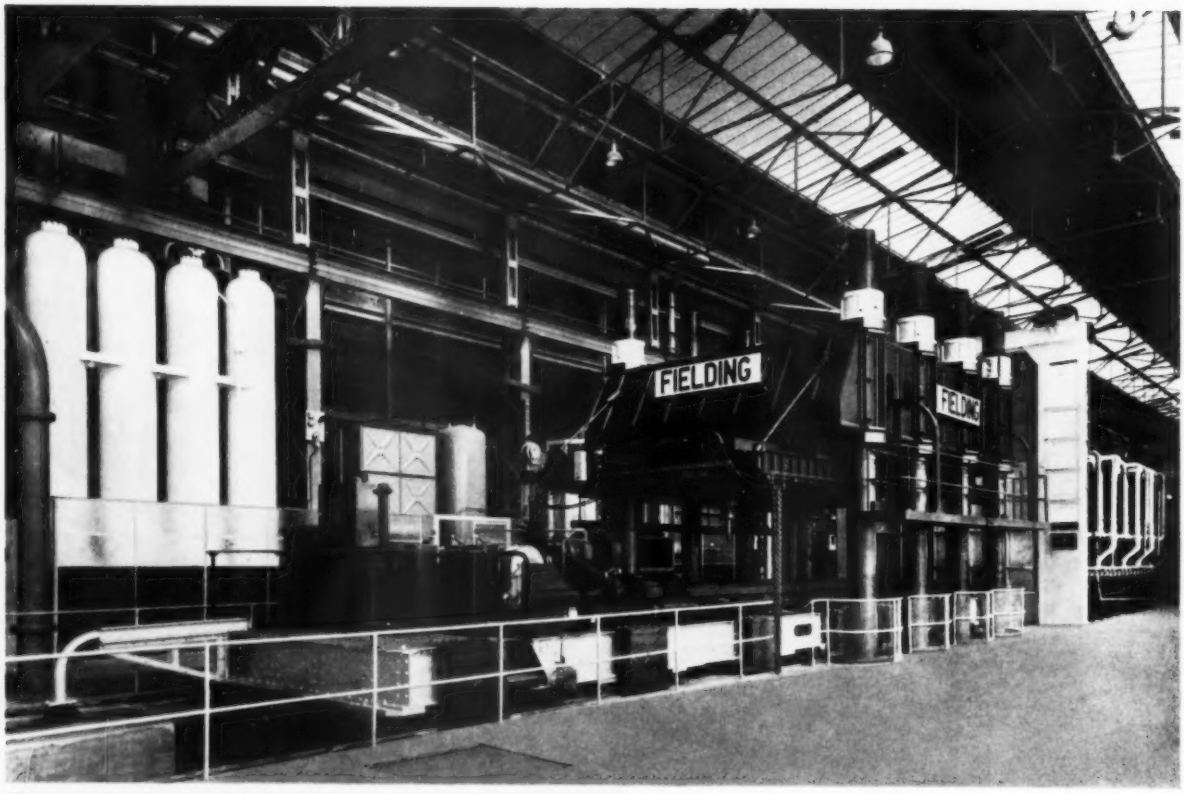
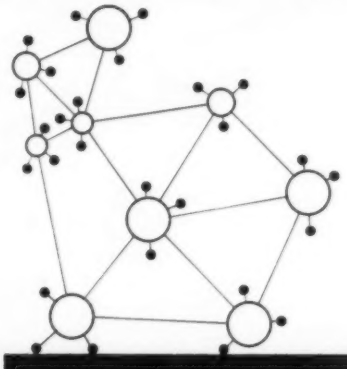


This press has been supplied to the Whessoe Company of Darlington for the shaping of the heavy steel plates required for the shells of the large reactor pressure vessels of nuclear power installations.



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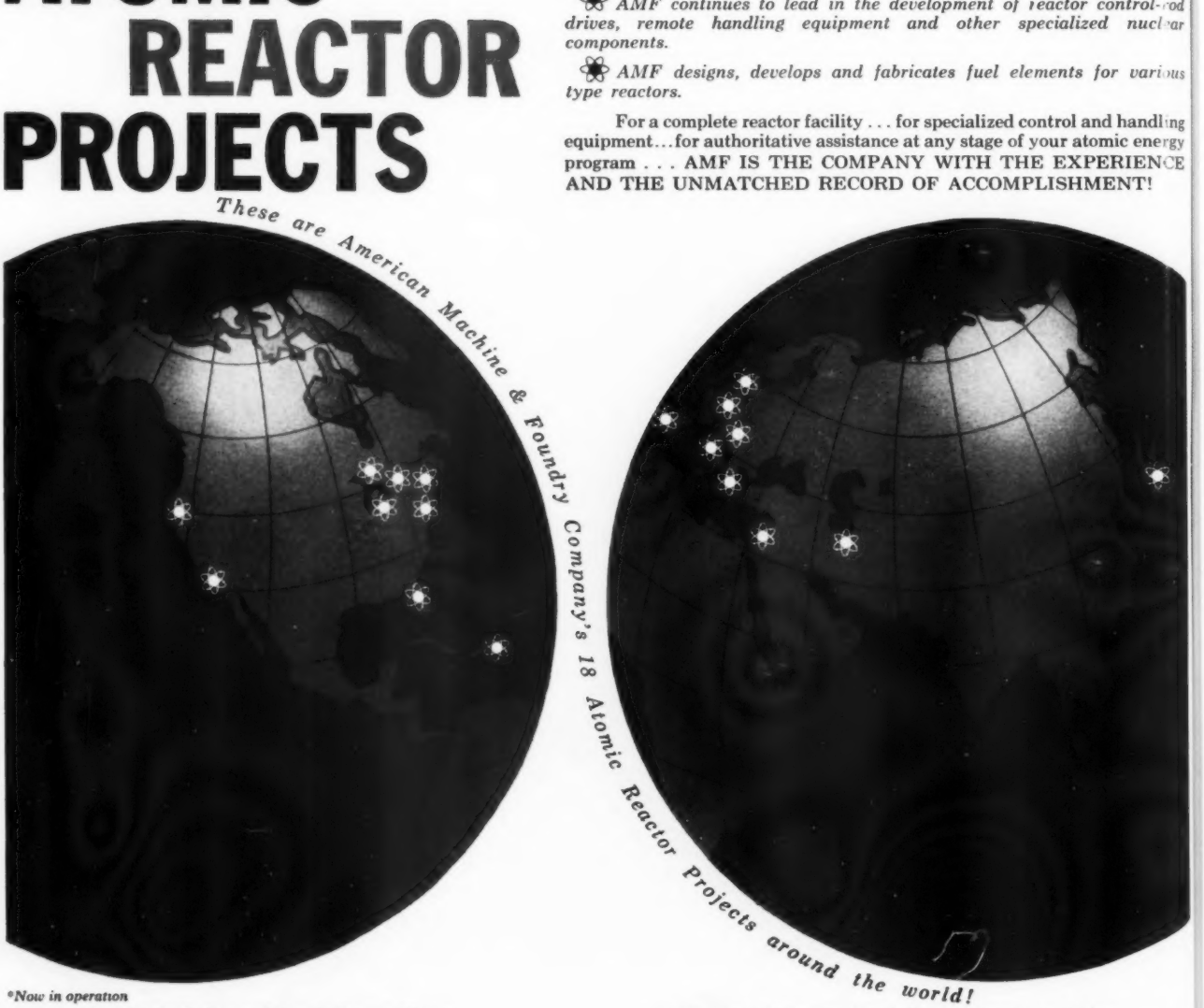

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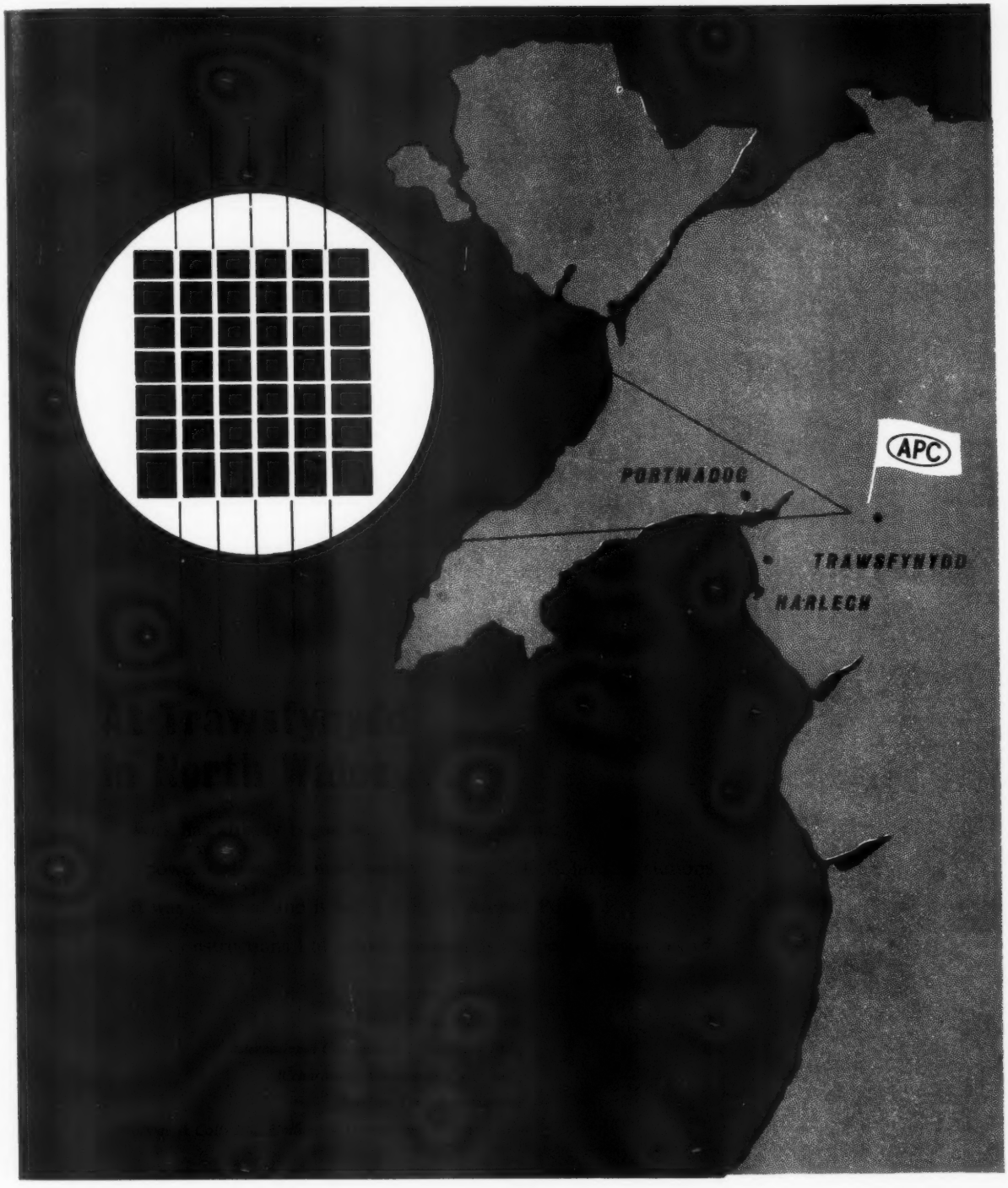

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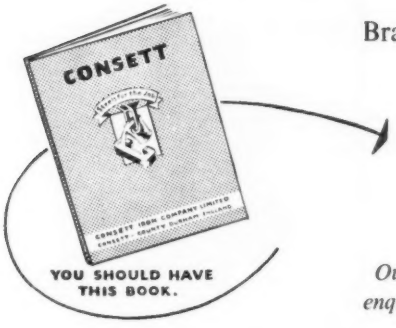

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Our Technical and Research Department will also welcome enquiries from any whose problem is . . . **STEEL**

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"Well, you see Johnny, it's because *your* sort of magnet can't be switched 'on and off'!"

"*Huh! I wouldn't like mine to do that!*"

"I know, but then you don't use yours to control water or gas and things."

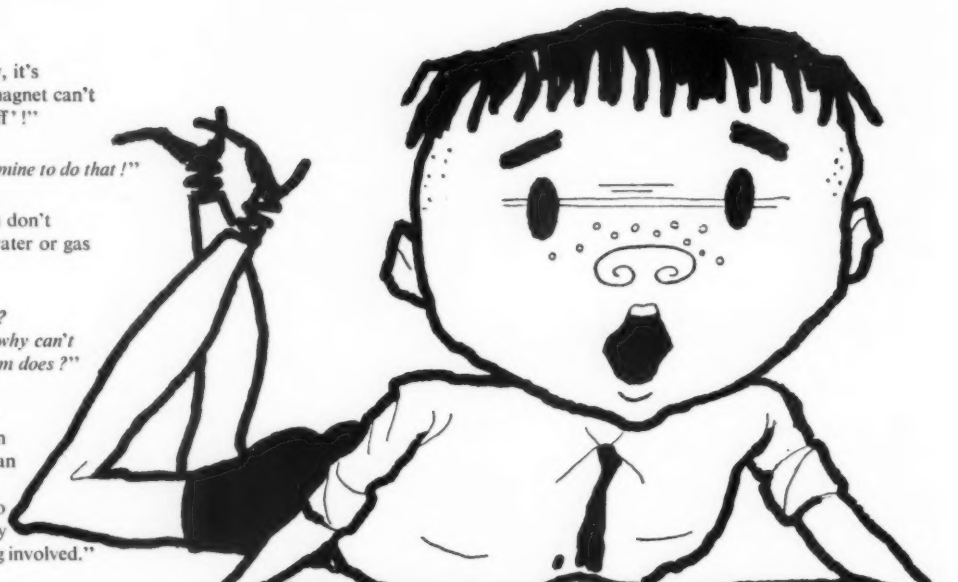
"*Control water or gas? Seems stupid to me — why can't they use a tap like Mum does?*"

"Ah! But using a tap means that you rely on what's called the 'human element'. That's why these valves are fitted to do things automatically —without people being involved."

"*Mr. Stevens told me they make chocolates with them!*"

"That's right, but not exactly to *make* chocolates, to *help* make them. Mushrooms, too!"

"*Cor! I like mushrooms.*" *(Throwing away magnet)*
"*Can I have some for tea?*"



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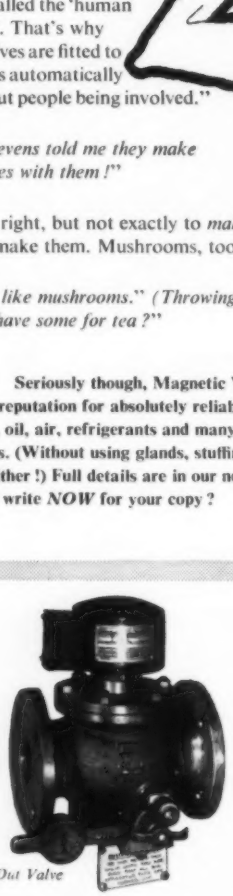
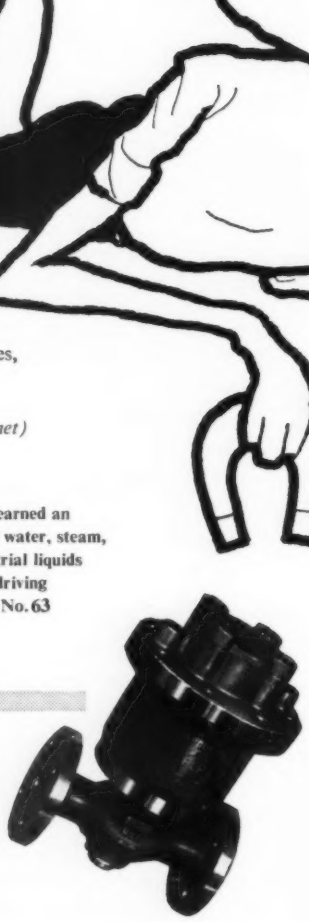
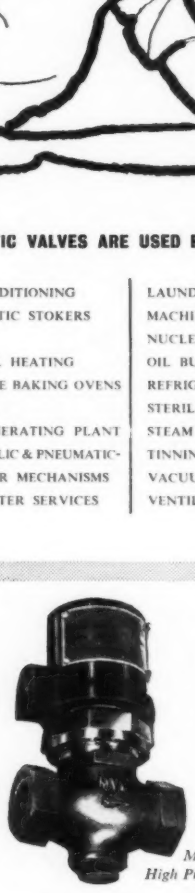


Magnetic Safety Cut-Out Valve



Magnetic Single-Beat Stop Valve with Flameproof Solenoid Enclosure



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MVC

The Magnetic Valve Company Ltd

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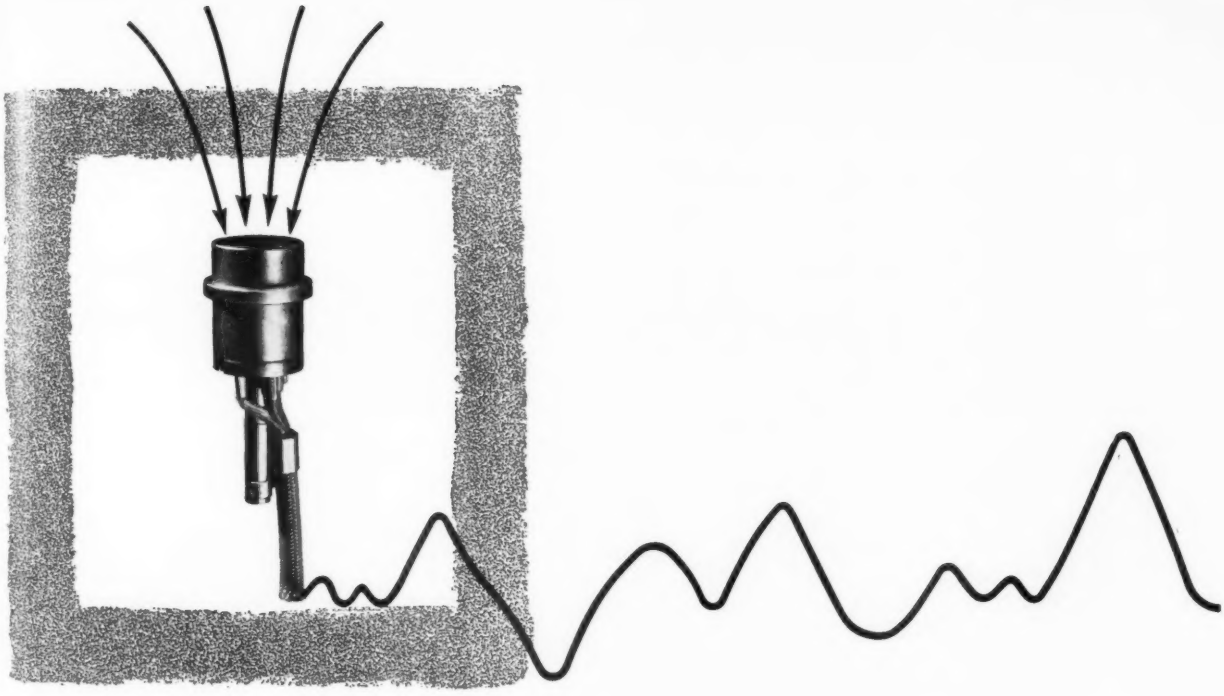
MV1



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BRIEF SPECIFICATION

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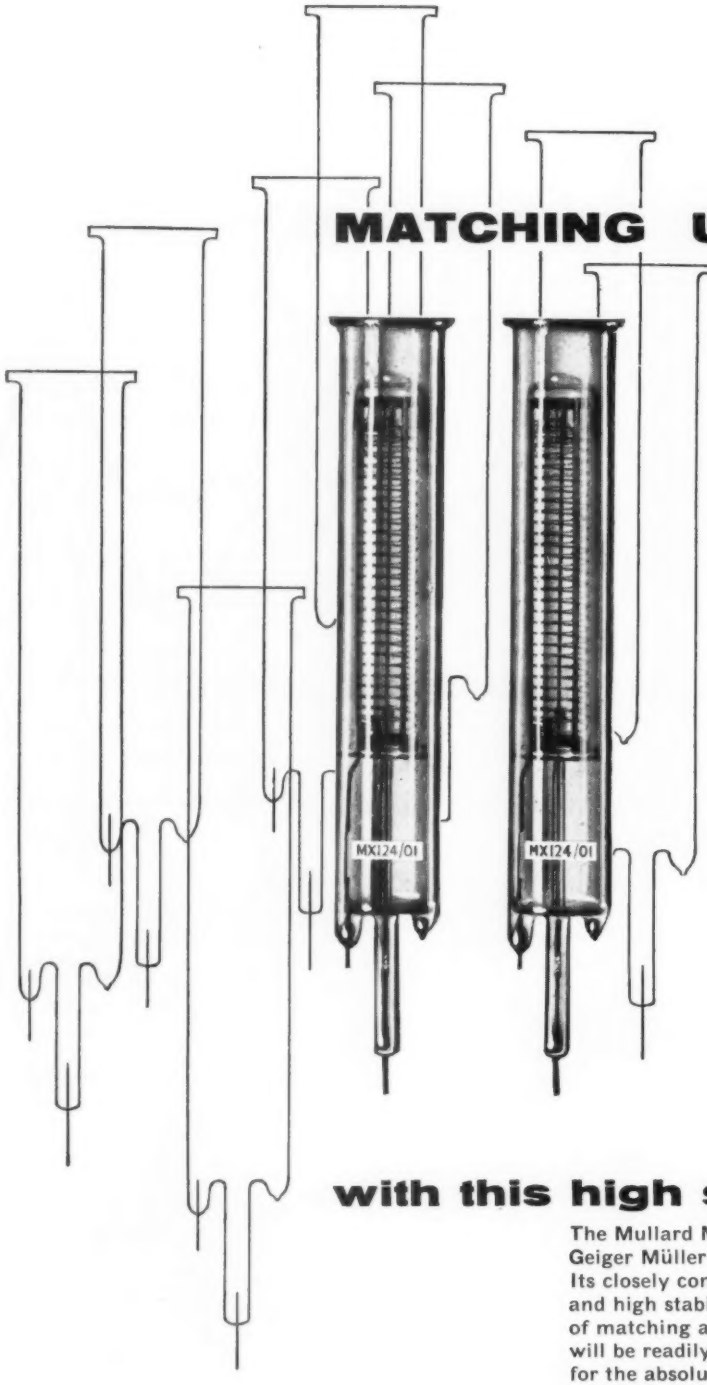

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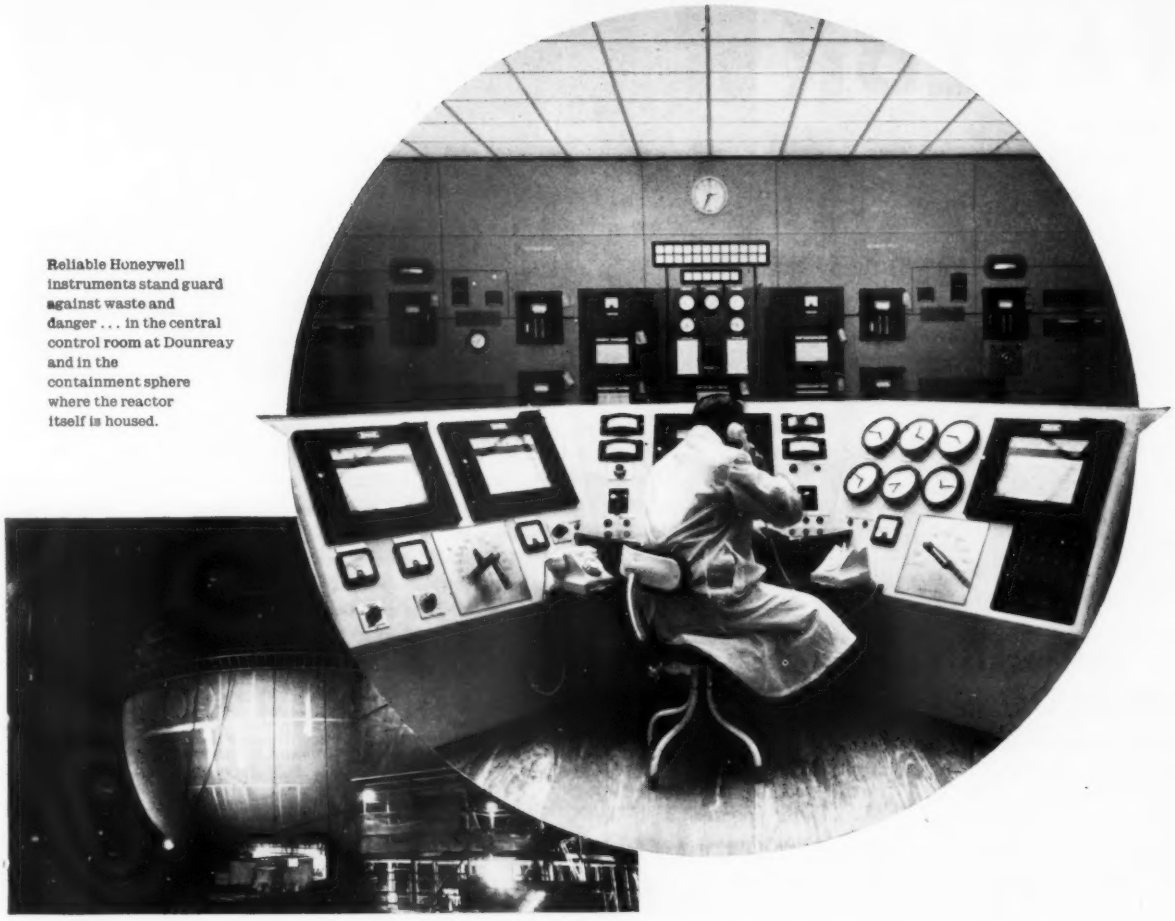

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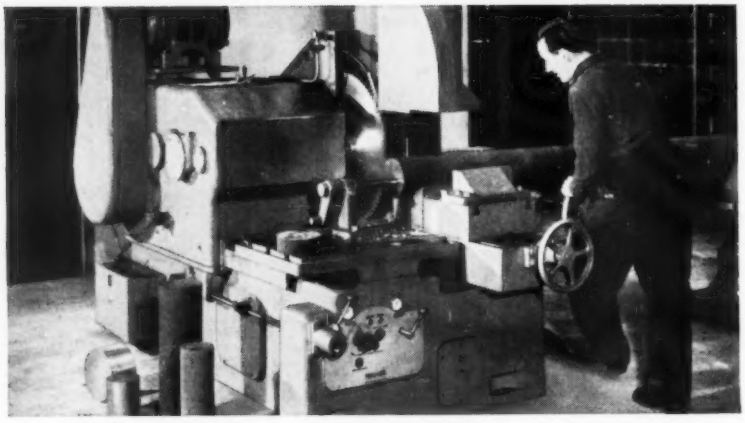

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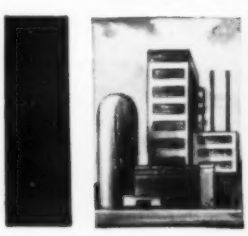

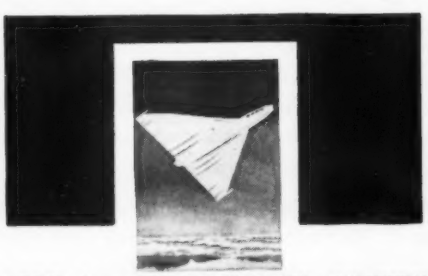

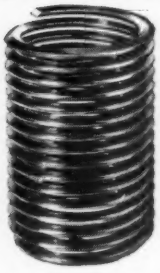

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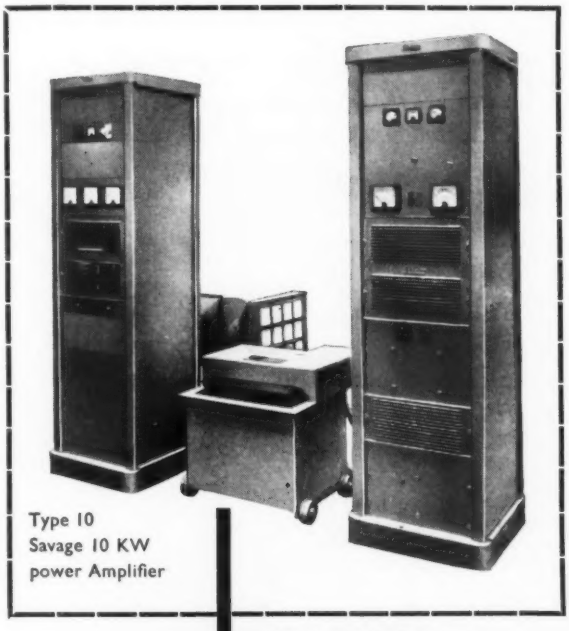

Type 10
Savage 10 KW
power Amplifier

SAVAGE AMPLIFIERS are suitable for driving 60 cycle American equipment; 400-2500 cycles for aircraft equipment; ultrasonic power supplies for cleaning, drilling etc.

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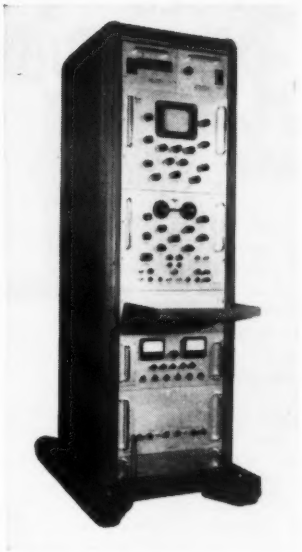

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MARSHALL
TWIN-CHANNEL PULSE GENERATOR MODEL T·P·G·100

Designed as a universal instrument for the development and general testing of electronic equipment. Extreme flexibility in use is achieved by virtue of the complete independence of the two channels apart from a common repetition frequency. The output pulses are fast-rising, of clean waveform, and at low impedance level.

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A pre-pulse is provided for the purpose of triggering auxiliary apparatus

The "A" and "B" channel output pulses are independently variable in amplitude, duration, risetime, delay relative to the pre-pulse and polarity.

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—with the type TCVR voltage regulator

The TCVR is a servomechanical automatic voltage regulator having the very high speed of correction of FORTY VOLTS PER SECOND. It provides an *undistorted* output, maintained constant within very close limits (normally ±0.5%) from no-load to full-load, for wide variations in frequency and power factor.

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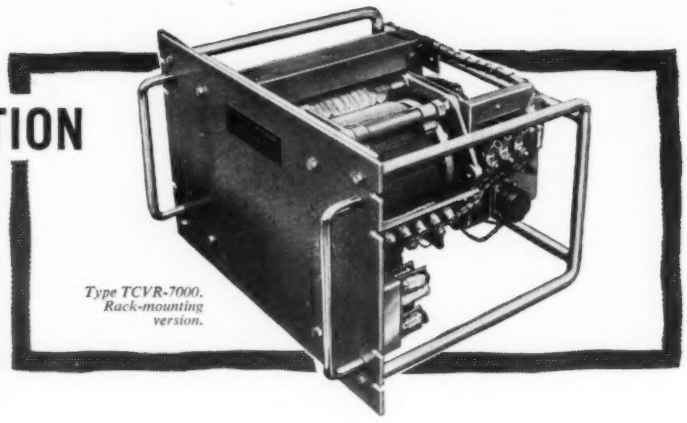
For high-speed, accurate stabilisation *without distortion*—**specify TCVR.**



Type TCVR-7000. Rack-mounting version.

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BMVR: Motor-driven laboratory and industrial regulators ranging from 1·6 to 29 kVA single-phase, and 4·8 to 87 kVA three-phase. Constancy of output normally ± 0·5%, from no-load to full-load. No distortion. Speed of correction 1 Volt/Sec. A great variety of models, standard, tropical and militarised, for all applications.

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High Vacuum Specialists and Electrical Engineers

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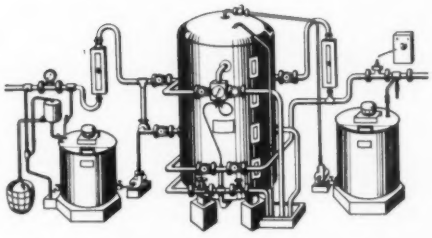

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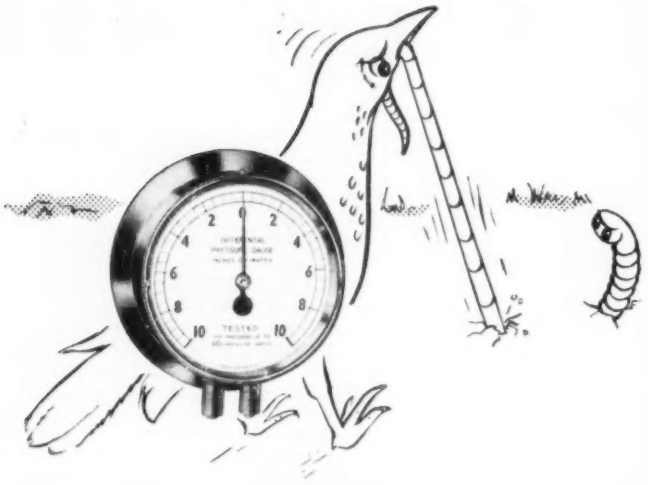

That's how it is just now—but, in the end, the thrush has the greater pull and if it were possible to connect their efforts to a P & G differential pressure gauge, the difference would be evident at once.

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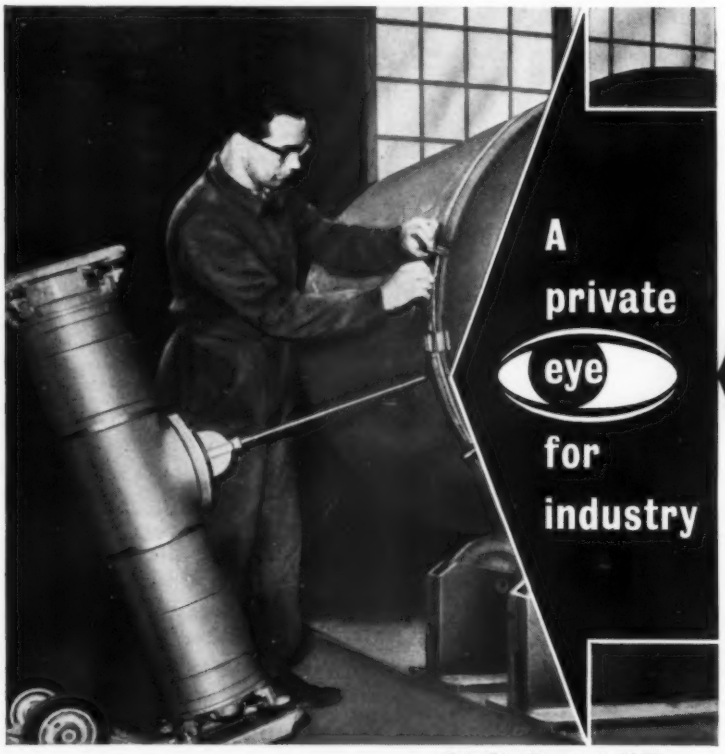

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(RCL0416A)

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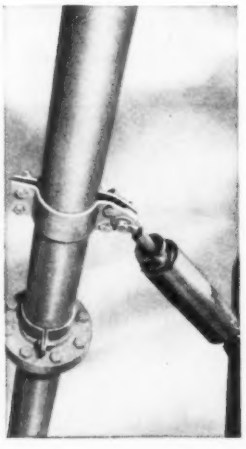

Shocks and vibration give rise to high stresses in pipework, with possible subsequent damage to piping and associated equipment. Pipework on board ship subjected to vibration or in land installations exposed to high winds, is particularly prone to these hazards.

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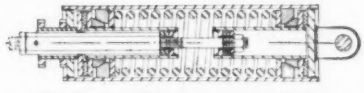
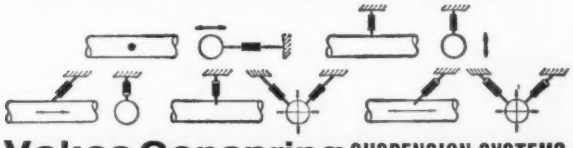


Vokes Genspring Non-Resonant Sway Braces

Sketches of suggested methods of application



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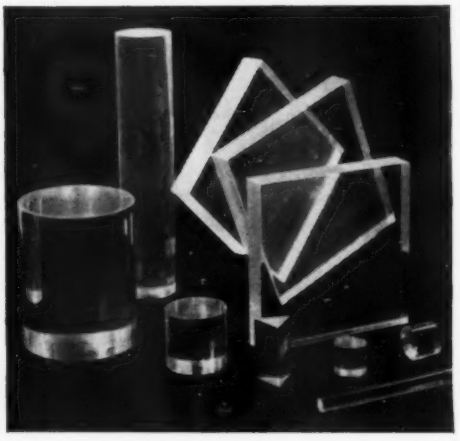

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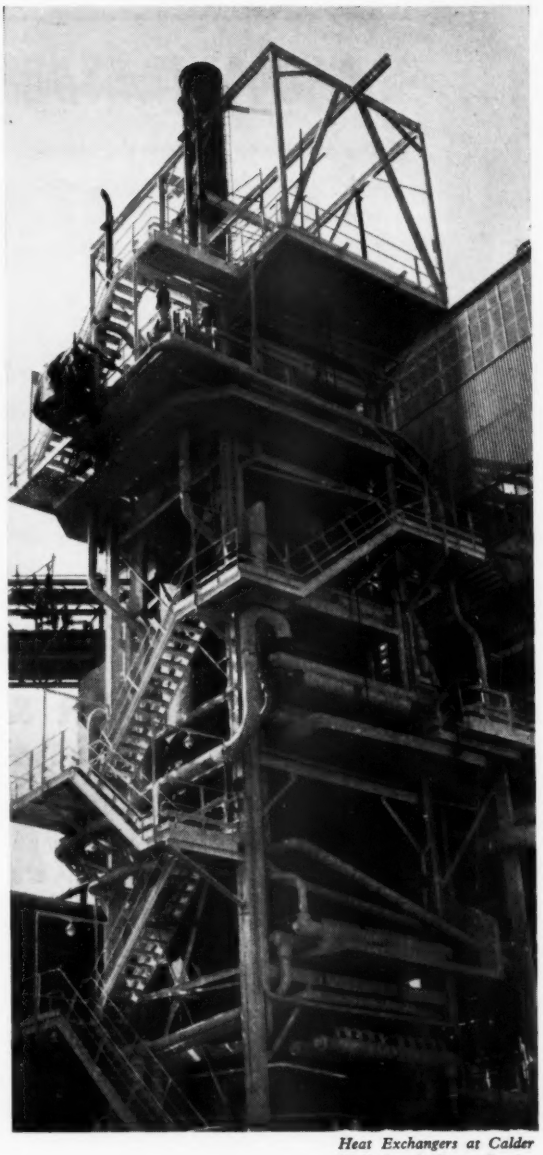

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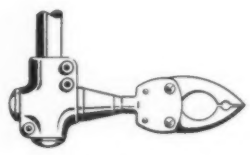

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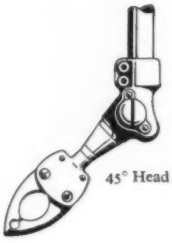

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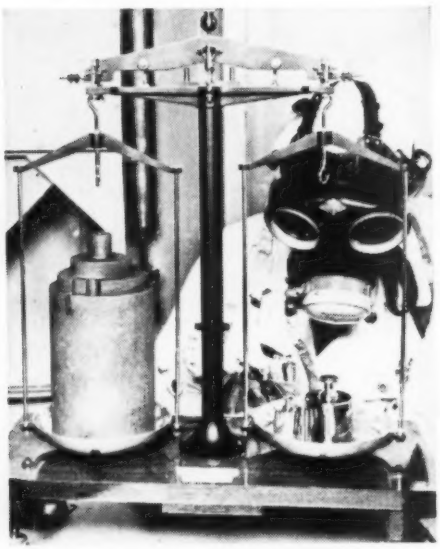

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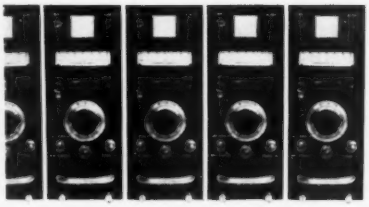

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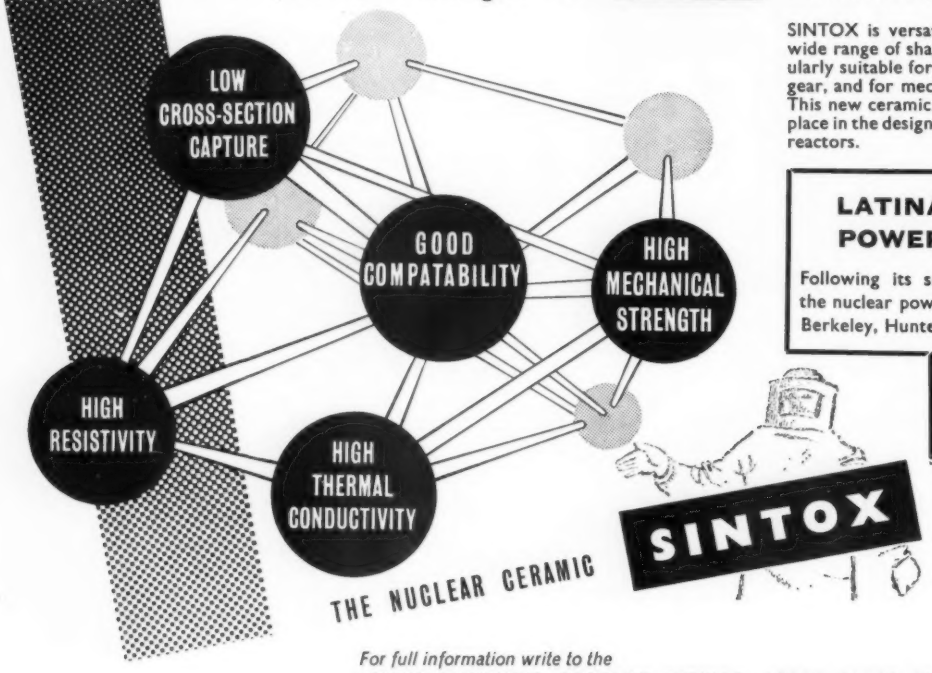

SINTOX is versatile in the production of a wide range of shapes and sizes and is particularly suitable for insulating parts in control gear, and for mechanical support members. This new ceramic has already taken a leading place in the design of components for nuclear reactors.

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Following its successful application in the nuclear power stations at Bradwell, Berkeley, Hunterston and Hinkley Point SINTOX is now being incorporated in the design for the Latina Nuclear Power Station.

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To provide a comprehensive welding service Milne also offer Electric Arc and Resistance Welding Plant and Equipment.

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Manufacturers of Gas Welding and Cutting Plant and Equipment
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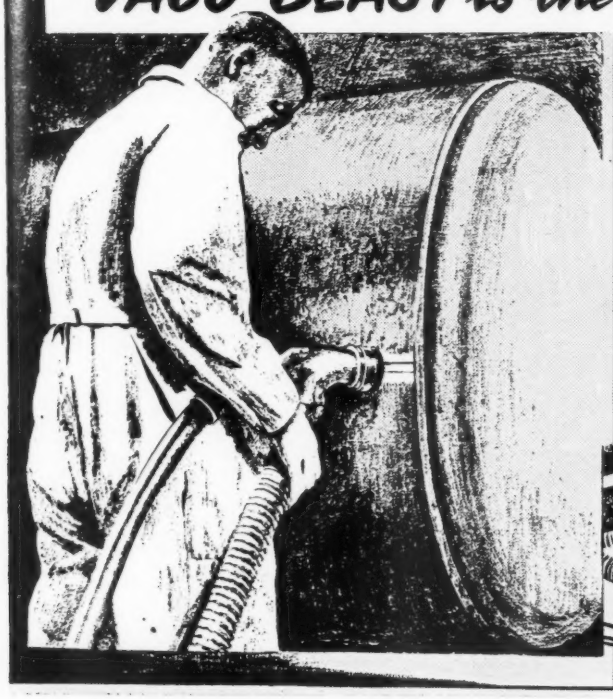
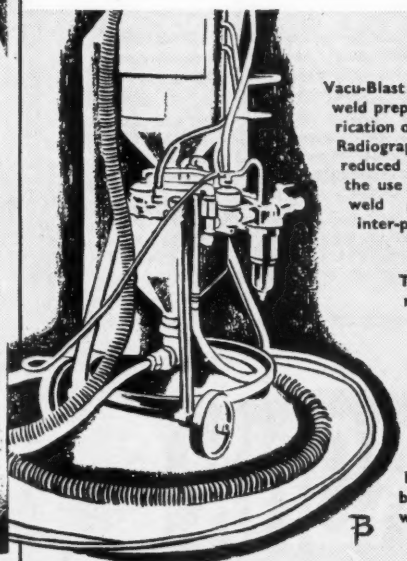
VACU-BLAST is the pre-requisite of all good welding





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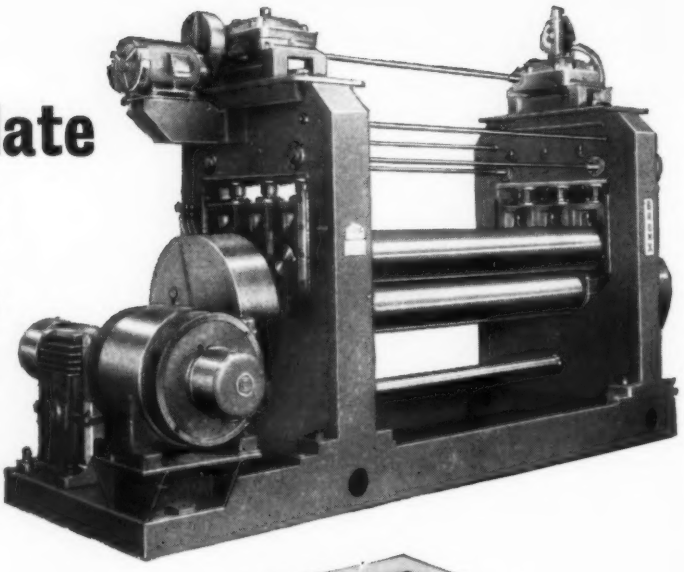
For levelling Mild Steel Plate



This Bronx 5-Roll Plate Levelling Machine is suitable for levelling cold mild steel plate up to a maximum of 8ft. in width by ¾in. thickness, and is designed for a levelling speed of 16ft. per minute.

The levelling rolls consist of three top and two bottom rolls, all of which are 12½in. diameter. The roll necks are finished ground, and the bearing assembly so arranged as to preclude entry of scale and other foreign matter.

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X-Ray head—84 lbs.

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'Baltospot' units give more KV per LB.

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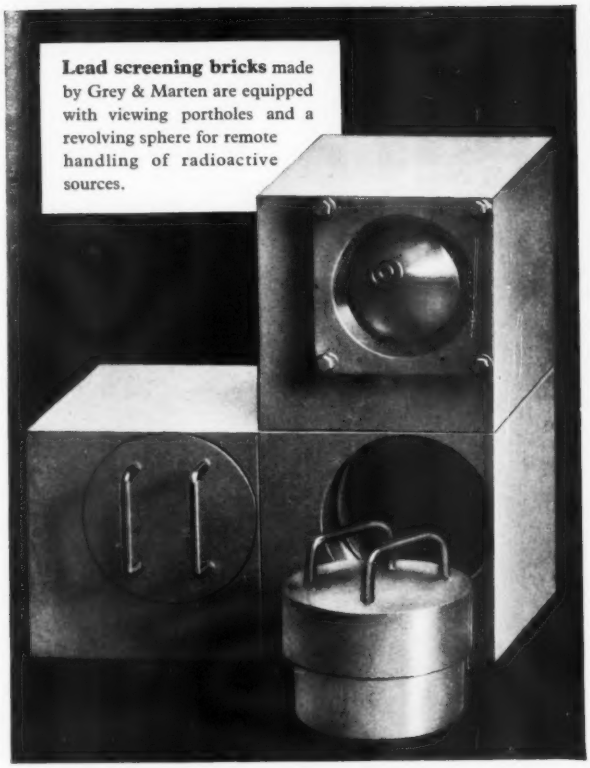
PANTAK LIMITED

VALE ROAD, WINDSOR, BERKS. **Telephone: WINDSOR 3225-6**



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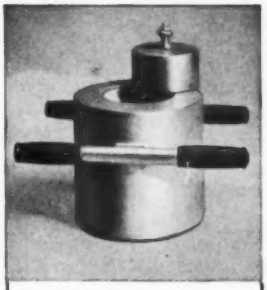
(Their new subsidiary, James Girdler & Co., has all their skill and experience)

GREY & MARTEN are experts in lead. They've specialised in the manufacture of *all* kinds of lead castings, fabrications and fillings for more than a century. Interlocking Lead Bricks (in one, two and four-inch thicknesses), Lead Sphere Units (in two and four-inch bricks), Aperture and Viewing Bricks, Lead Pots and Isotope Carriers are all produced under the Grey & Marten name. Now they have handed over this activity to their new subsidiary, James Girdler & Co. Ltd.



Storage pot typical of those used in standard safes not already fitted with lead protection, affords economical storage for radio-active material.

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DISPLACEMENT RANGE 1 to 136 c.f.m.

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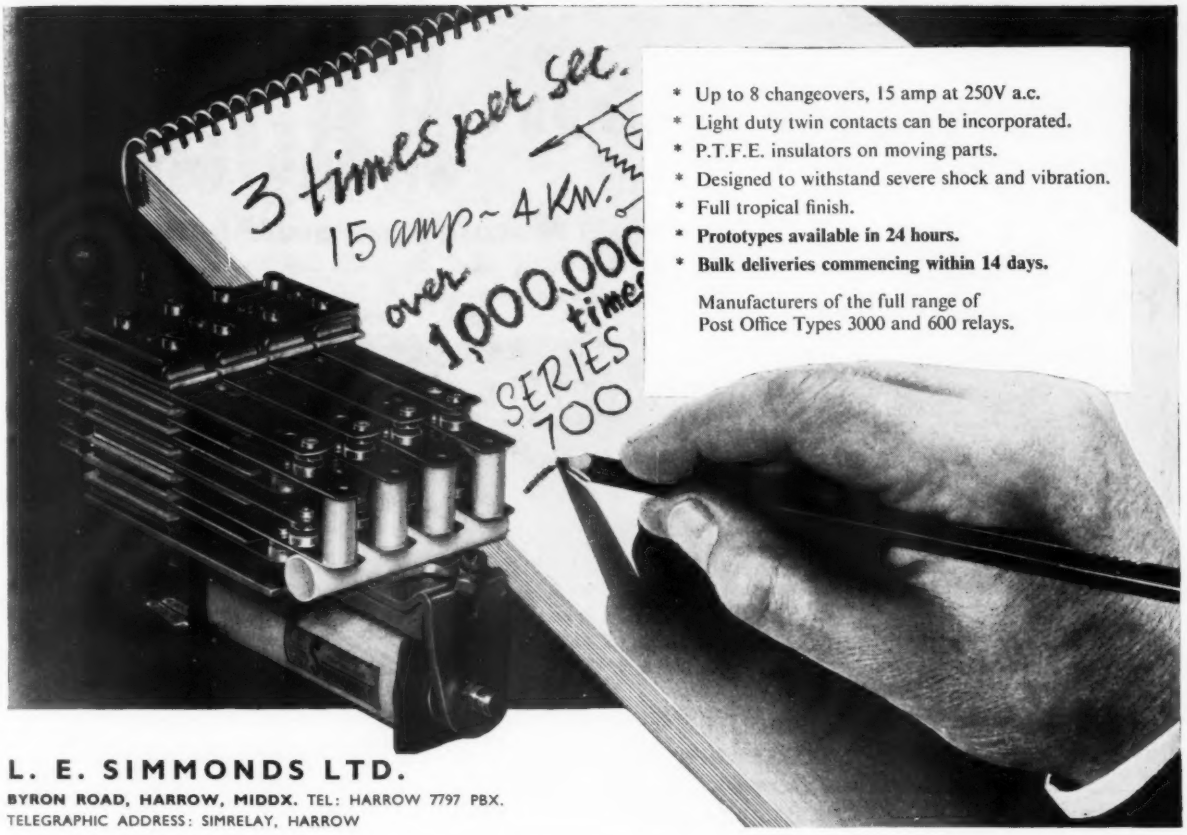

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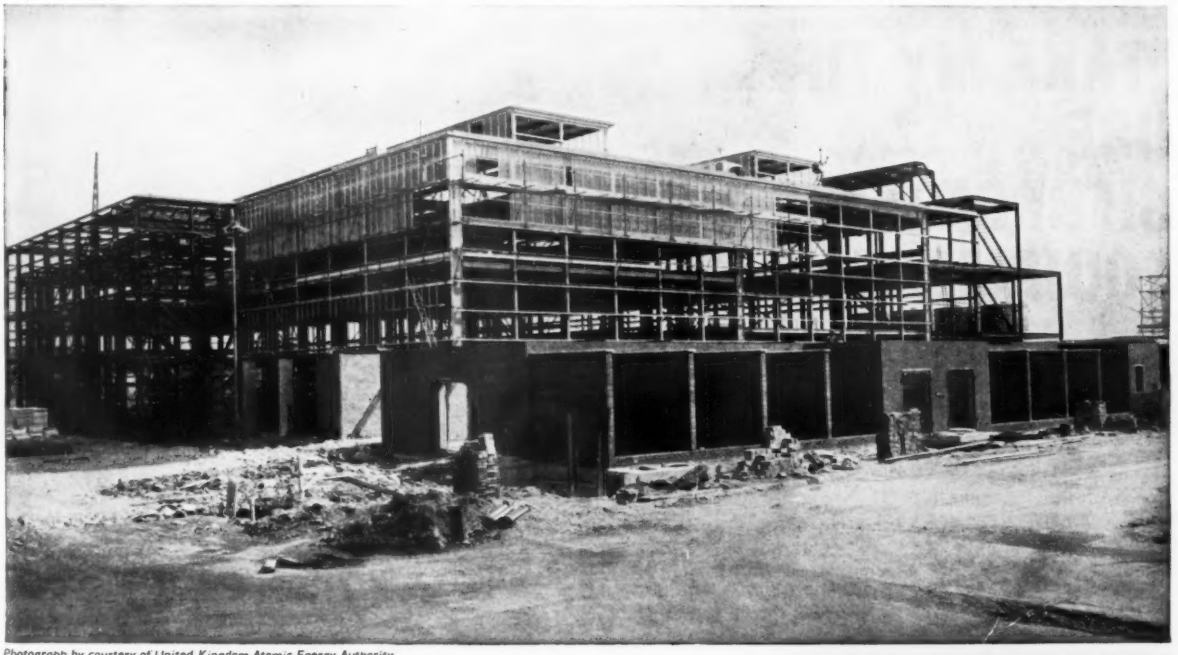

Photograph by courtesy of United Kingdom Atomic Energy Authority

Ore Store, purification and blending buildings at Springfield Uranium Plant, Lancashire

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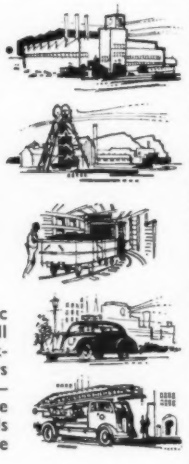

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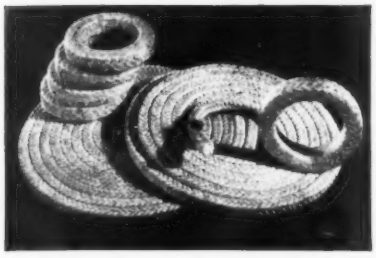

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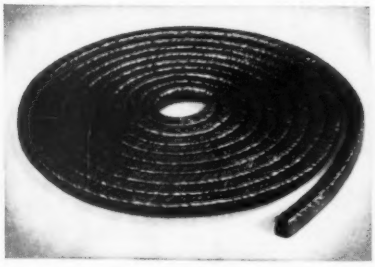

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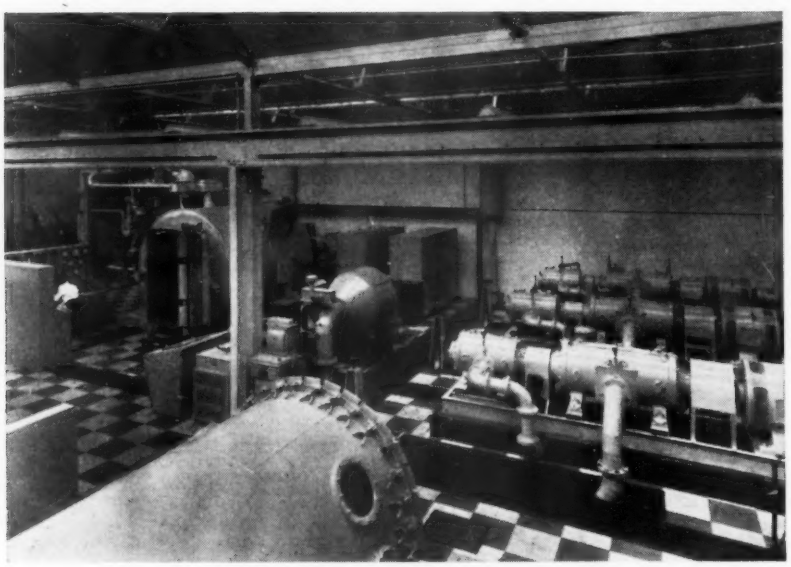

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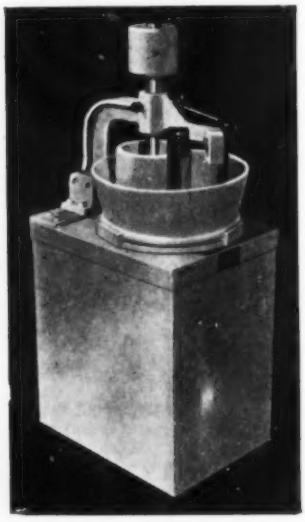

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Available with four mortar sizes, 7", 10", 15", 20". Mill supplied complete with electric motor and starter and with either ceramic or metal mortar and pestle.

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The model illustrated is the No.2 mill with a 15" diameter mortar

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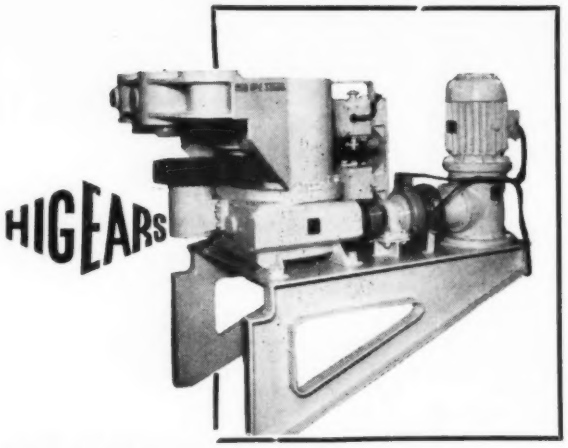

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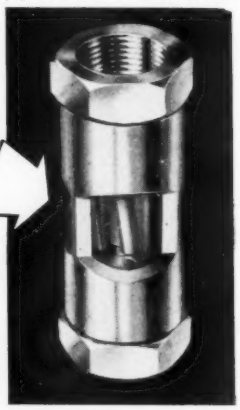

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Note these features

- *Simple design ensures complete reliability.*
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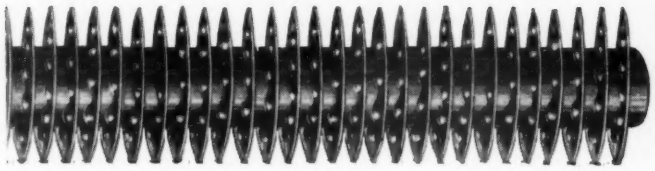

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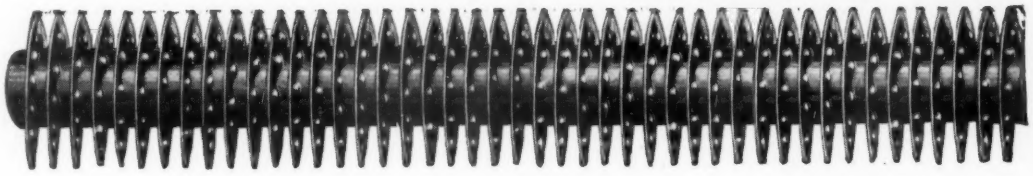

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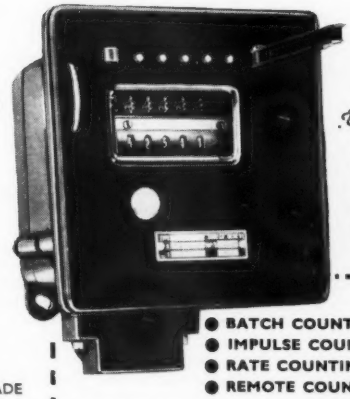
starts with counting



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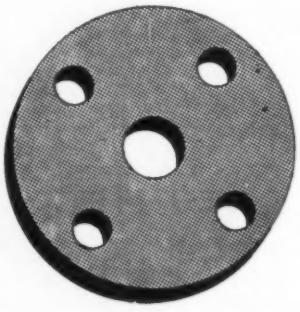

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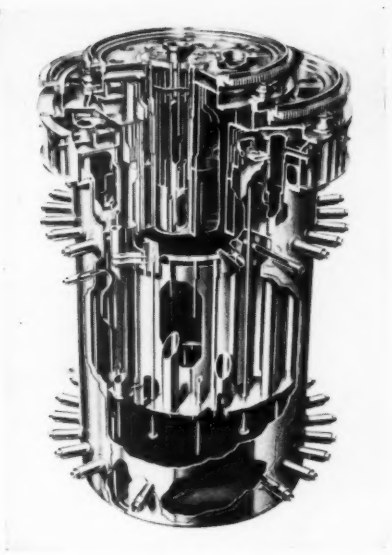

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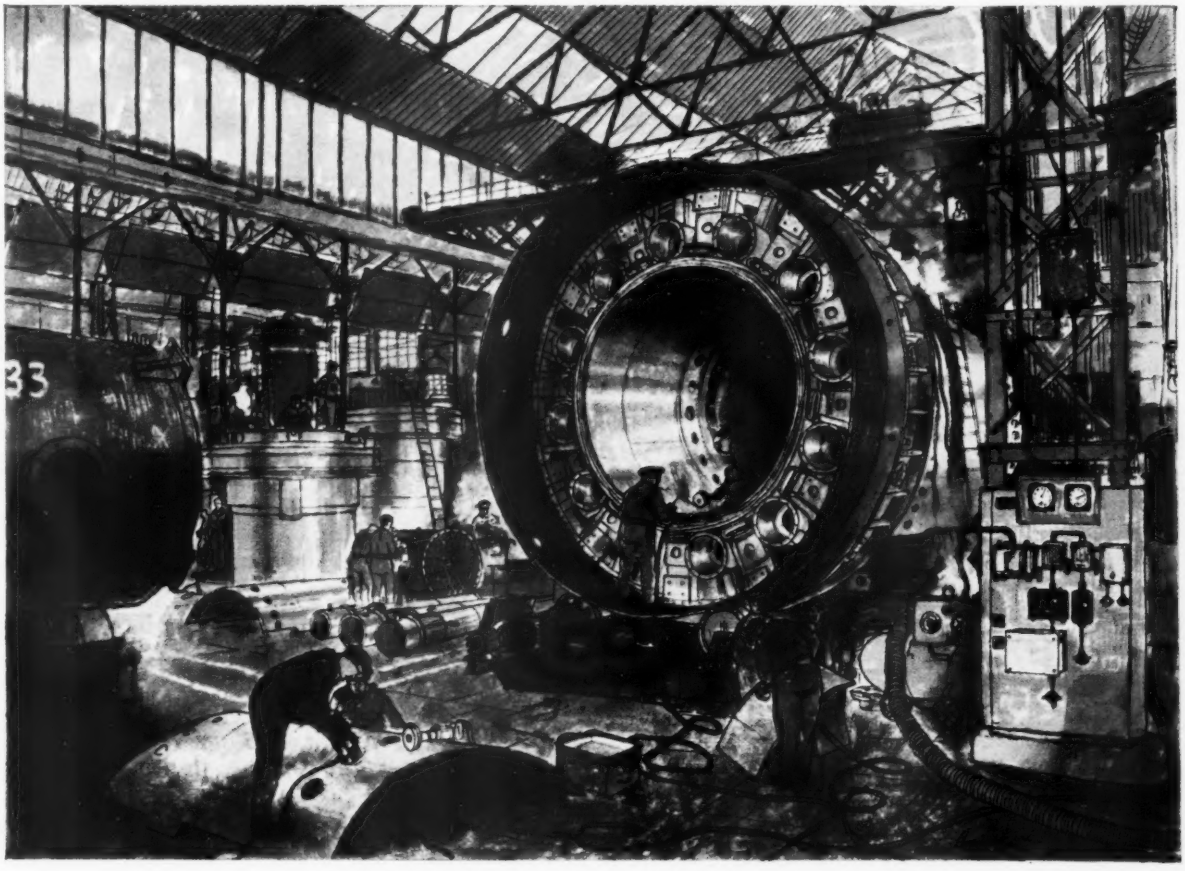

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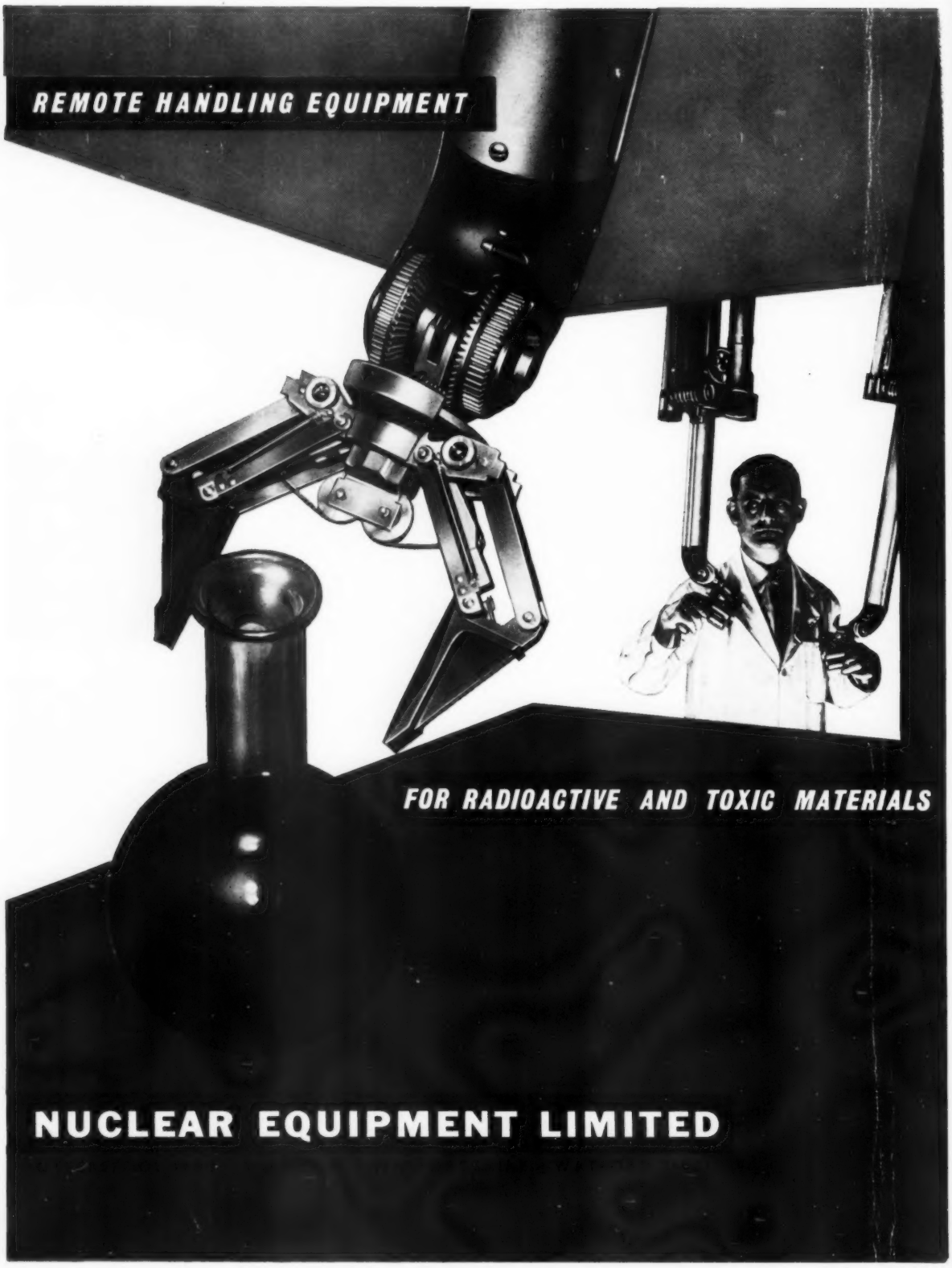
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